The Living Sonars of the Ocean

by

B. F. SERGEEV

Mir Publishers
Moscow

The Living Sonars of the Ocean

Б. Ф. Сергеев

Живые локаторы океана

Гидрометеоиздат Ленинград

The Living Sonars of the Ocean

by

B. F. SERGEEV

Translated from the Russian
by
M.B. Rosenberg

English Translation Edited
by
R.N. Hainsworth

Mir Publishers
Moscow

First published 1985
Revised from the 1980 Russian edition
На английском языке

© Гидрометеоиздат, 1980
© English translation, Mir Publishers, 1985

Contents

Mischievous Nymph *7*

Toward Mastery *9*

Using Aesculapius's Method *9*
Difficult Offspring *12*
Slobberers *16*
Squeaky Babies *20*
Pioneers in Hydroacoustics *31*

Whales-Acousticians *36*

The Voice of the Ocean *36*
Dolphin Primer *41*
Baby-Whales *48*
Eccentrics *52*
Unicorn *58*
Arctic Canaries *64*
Not only Auks *68*
Blue Miracle *72*

Live Searchlight *78*

Maxi, Midi, Mini *78*
Whence? *83*
A Bright Star in the Forehead *90*
When Your Head Is All Bumps *95*
Secret Code *99*

Imprisoned Wave 103

How to Ask Questions 103
All that Occurs in the World... 106
What does a Hare Need Long Ears for? 109
The Entrance to the Labyrinth 114
Holy of Holies 116
Patent Retrieval 124
Astride the Waves 132

The Black Box 137
The Emperor's Clothes 137

From the End of the Nose to the Tip of the Tail 141

One Image 146
Who Is Louder? 149
Mustache, Whiskers, Beard 153
Parrots Only Talk in Cages 159

Rivals 172

Cows-Divers 172
Lions, Elephants, Leopards 181
Recruits 199
Winged Pedestrians 206

The echoes of human voices whisper mysteriously even in a nearby wood. It is louder in a deep gorge or in a cave. You can imagine what a strong impression echo made on people when they did not know what caused it. In Greece there are numerous grottoes and temples where a sound repeates itself many times under the arches. The ancient Hellians could not leave this incomprehensible phenomenon unnoticed. The Greeks produced many legends trying to explain who was mimicking human voices and why. One legend blamed Hera, the Queen of the gods, for this. The legend recounts that Hera deprived the charming nymph Echo of the gift of speech because Echo had distracted her by talking to her while Zeus, her husband, flirted with other nymphs. Once she realised that she was being fooled by words. Hera flew into a rage and punished the nymph severely. Since then Echo can only repeat the ends of the words she heard. The miserable nymph wanders alone in gloomy caverns, in damp deep gorges, along the banks of lakes and brooks, hiding from everyone in the shadows of shore cliffs or in the cover of forests. If she sees a traveller, she tries to call him, but alas she can only mimic him. Tears spill from her eyes and suppressing her sobs, Echo rushes away into the green darkness of the forest.

However, the phenomenon of echo is quite real and physical, and one that scientists have only recently understood. It has taken centuries to study even the most elementary

properties of sounds. Nature is far more capable. It has taught animals to employ echo skillfully. When they sent out sounds, they could not but notice the constantly appearing echo. It would have been unnatural if this free gift of nature were wasted. The animals had to learn how to understand the information contained in the echo, and then improve their hearing and vocal apparatus. Humanity has grasped the possibility of employing echoes only in the last few decades. The quality of man-made devices is only today approaching the designs of nature. We still don't understand many things. This book discusses the bioacoustical "patents" of the nymph Echo and humanity's study of them.

Toward Mastery

USING AESCULAPIUS'S METHOD

Science and industry are developing at an ever accelerating and unparalleled rate. Their investigation methods and technological processes are almost completely renewed each decade. You would be a laughing-stock if you were to propose exploiting methods practised a century ago. Only one branch of human knowledge has lasted the centuries, preserving many of its methods and rules intact. This is medicine. Some of its methods of examination and even treatment were known long before the construction of the Egyptian pyramids! Two of these, namely, auscultation and percussion, are applied today even though they were used long before medicine became an independent branch of science. A doctor uses these methods whenever you visit him.

The term "auscultation" means "listening to". The condition of various human organs can be judged by the character of the sounds they produce, for example, the sounds in your lungs while breathing, or those in your heart as it pumps blood. The Latin word "percussion" means "tapping". A physician taps the patient's body with his finger, or taps a finger on his other hand which is pressed to the chest of the patient. Sometimes a small hammer and a plessimeter (a special plate pressed to the patient's body and tapped) are employed. The tapping causes pendulum-like oscillations in the thoracic wall and in the organs beneath it, i. e. it generates sound. If the organ being examined is healthy, the oscillations are periodic and their number is

constant per time unit. They are heard as tones. When the internal organs are not healthy, the oscillations have different frequencies and amplitudes in different parts of the organ. We hear all these oscillations together as noise. It is unnecessary to hear well to gain an idea of the object in question. If we wanted to find treasure in an old building, we would tap out the walls first and so would discover any hidden cavity. Animals do the same quite frequently.

The animals inhabiting our planet acquired hearing after they had developed vision or the organs of balance. Sounds of biological origin, generated by animals, only appeared when they learned to move around, and started to travel over the world and to devour each other. This factor promoted the appearance of a sound analyzer in animals, in other words, the emergence of ears. The animals had at the same time to learn to be quiet, since this was beneficial both for a predator sneaking up and for hiding prey. In consequence, their ears sometimes had no work to do.

Nature never tolerates anything useless and so the sound analyzer was applied to other things to reduce the working time losses. If the object did not produce sounds voluntarily, it could be forced to do so. This is exactly what priests in ancient Egypt did when examining a patient. Animals do something similar. Bats and dolphins have developed the most in this respect. They "tap" space with ultrasonic pulses, and many animals do the same.

Some animals behave like experienced treasure hunters, but they are in a better position than people because they hunt for living treasure, which can always give themselves away by a random rustle or an escaping sound.

The jungles of Madagascar, like other tropical forests, are a kingdom of humidity, decay and wild life. But there are neither dangerous predators, nor noisy monkeys in this jungle. The dark forest is, however, where the relatives of the monkey—the lemurs—live. They are the most astonishing creatures in the world. More than 20 species of them reside

on the island, and the most interesting one is the ring-tailed lemur, which is also known as the ai-ai.

The ai-ai is a small animal about the size of a cat. In habits it resembles a small monkey with a fluffy squirrel tail. The ai-ai has a clever face and large eyes that are characteristic of nocturnal animals. The large ears are turned forward as if the animal is always listening to something. And indeed, hearing is of paramount importance in the life of this lemur because impenetrable darkness reigns beneath the crown of the tropical forest. Only the senses of smell and hearing can help this little creature.

The fingers on its hands are the most surprising because they are unnaturally long and extremely thin. This is especially true of the middle finger which looks as if it has been withered by a terrible disease. It seems that the finger is devoid of even a single ounce of muscle. This finger is very important in the life of a lemur. When the heat of the day drops and the darkness of night blankets the Madagascar jungles, the ai-ai wakes up in its large and comfortable home. Having completed its "morning" toilet, the animal begins to think about breakfast. Searching for something edible, it goes to a nearby old tree and begins to examine the trunk very carefully, tapping it with its long fingers and listening carefully to the generating sounds just like a doctor does when he percusses the chest of a patient.

Many bark beetles live in tropical forests. Their larvae leave long twisting passages in old trees, and it is the larvae that the lemur is interested in. Having detected a cavity by sound, the ai-ai begins to follow all the twists of the burrow until it comes to its end where the maker of the maze is hidden. The ai-ai taps this spot very carefully until it is sure that the larva is there. Then it bites into the trunk with its sharp teeth and makes a hole a second later in the castle wall of the recluse. The ai-ai sticks its thin finger into the hole and extracts the resisting host. Breakfast is ready. When the lemur has devoured the larva and thor-

oughly "washed" its hands, it continues to examine the tree infected with bark beetles.

The ring-tailed lemur is not the only treasure hunter in the animal world. Woodpeckers possess refined hearing which assists them in their search for food. These birds have a straight, strong beak which is as sharp as a good chisel, a hard tail and strong claws. Climbing up the tree trunks, the bird peeks into every slit and crack in the bark. The woodpecker, too, feeds on the larvae of bark beetles. The bird employs its hearing to detect the larvae. The feathered carpenter slowly taps the tree trunk, inclining its head to the right and the left. Evidently, it hears better in this manner. When it finishes the percussion of its patient and learns the pattern of the passages gnawed by the insects, the forest doctor begins its work. Large pieces of bark drop to the ground for two-three minutes and deep holes appear in the trunk. Now it is possible to take a bite of a fat larva.

DIFFICULT OFFSPRING

It happens sometimes that children grow up considerably taller than their parents. This presents no trouble for us but it is much worse in the case of animals. The South American goatsuckers—the guacharoes—are a typical example. These large birds have a wingspan of about 1 m. The weight of their two-month old nestlings, although still having no plumage, is twice that of their parents. Their weight is not due to muscles; a young guacharo is like a bag of fat, which is the reason for their other name—fat goatsuckers, or simply fatties. From time immemorial Indians have gathered guacharo nestlings and putting string through their bodies, they have hung them to dry in the sun, using them afterwards as candles.

I can give no reason why the guacharo needed such accelerated development, but one point is quite obvious: the fat children set very difficult problems for their fat parents. The

first is the feeding problem. The nestlings must eat a great deal in order to grow quickly. This would present no problem if the guacharo were a common granivorous bird. However, all the 96 species of goatsuckers spread throughout the world feed themselves and their nestlings on insects which they catch on the wing. It would certainly be impossible to store enough insects for such gluttons and the guacharo had to switch over to vegetation, which is unusual for these birds, and to find the most delicate food possible. They choose the fruit of the oil palm tree and most juicy and tender fruit.

But their feeding problem does not end here. Oil palm tree plantations are not very common and the birds must fly 70-80 km away from their nests in search of food. Besides which, guacharoes have not learned to perch on tree branches. They grab the food in flight, hovering in the air against the fruit clusters just like a squadron of helicopters. If it is considered also that the birds feed in the darkness (guacharos like all respectable goatsuckers are nocturnal birds), it becomes evident that the feeding problem is not an easy one for the fatties.

The second problem, which is of no less importance, refers to the protection of the nestlings. These fat and utterly helpless creatures stay in the nests for four months. This bag of fat is a desirable and easy prey for any predator, and the situation is aggravated by the fact that the parents leave their offspring alone for the whole night and fly away in search of food. The pitch darkness of large caves turned out to be the only reliable refuge. In caverns deep beneath the ground on tiny ledges right under the arch, sometimes 30-40 m above the cavern floor, a guacharo builds a small platform of debris, often the oil palm stones, and lays two eggs on it. No predator can reach them there.

By settling in deep caves, the guacharo has to manage without daylight. They spend the day in the darkness of their caves and leave it in search of food only when it is

dark outside. This caused the third and apparently the most complicated problem—to learn how to orient themselves in the darkness without colliding with tree trunks or cave walls, and how to find their offspring and food. The guacharo coped with this problem too. They behave like people who have lost their eyesight, but instead of using a stick to feel their way around, they do it by means of sound.

The remote ancestors of the fat goatsuckers "guessed" that every object can be made to generate a sound if they are percussed with... sound. A sonic pulse, colliding with an obstacle, rebounds like a ball and reverberates as an echo.

Europe learned of the guacharo from Alexander Humboldt, a traveller and biologist. On returning from South America, he described these amazing birds he had discovered in 1799 near Caripito in Venezuela, birds that flew around screeching in the darkness of the caves. No one seriously studied the fat goatsuckers for the next 150 years for nobody liked the prospect of studying birds in pitch darkness, or enduring the objectionable, sinister screeching and offensive odour, or sinking knee deep into the stinking dung that had accumulated in the course of centuries. The fat goatsuckers were only remembered when echolocation became a subject of scientific research, and a special team of researchers arrived in Venezuela from the USA.

Some animals have very good vision and can differentiate surrounding objects and feel themselves perfectly well in the darkness, which seems to be impenetrable. The scientists had first to check whether guacharoes used faint glimmers of light that penetrate the depths of their caves. The underground galleries of guacharo homes go down to a depth of 650 m. When they reached the very end, the scientists turned off their searchlights. It is known that our eyes do not accommodate immediately to darkness. However, even half an hour later the researchers saw no glimmers of light.

However, human eye is an unreliable indicator. There are many things that we do not sense, but a photographic plate

confirmed that the cave was really enclosed in absolute darkness. Nevertheless, the birds, alarmed by the intrusion of people, shot around the caves with loud screeches that multiplied in a series of echoes. The birds collided with neither the walls nor each other. Did the guacharoes use their screeching for echolocation? This had to be proved. The birds also emitted other sounds, which resembled clicks. They produced them in short series reminding of rolling drums. At twilight the fatties flew to the exit and the cave filled with the rolls of innumerable drums. They flew in silence into the open air outside the cave. The clicks resembled location pulses more than the screeching of the birds.

It was possible to determine under laboratory conditions that the birds can fly around freely in complete darkness without colliding with a wire stretched across the room. However, all the time they emitted series of clicks. When the light was switched on, the clicking stopped immediately because it was unnecessary in sufficient lighting. The ears of the birds were pasted then and they immediately lost all sense of orientation and the clicking was to no avail. The instruments indicated that the clicks were very short, the time interval equalling a thousandth fraction of a second. Each series consisted of 3-6 clicks, though sometimes more. The intervals between the clicks were also short, being only 2.5 times longer than the clicks themselves.

Sound propagates in air at a speed of 340 metres per second, i.e. 15-20 times faster than the speed of a flying bird. Hence, a sonic pulse collides with an object and reflects from it long before the bird reaches it, thereby warning it of an obstacle. The birds receive quick and exhaustive information on the upcoming sections of their route. The echo-sonar of the guacharo is not a very good instrument. Because the frequency of the acoustic waves of the location clicks is only 7,000 Hz, they are quite long—about 5 cm. Hence these signals are useless for locating very small ob-

jects, for example, a beetle flying around in the darkness. But guacharoes do not hunt the beetles. The stone arches in the caves are quite big and the fatties usually avoid them. They find their fruit using their excellent smell, a sense which is not usually well developed in birds.

Relatives of the guacharo—the common goatsuckers—inhabit Russian forests. They arrive in spring from the far South, i.e. from Africa and India, and then mysterious uerrrrrrrr... can be clearly discerned during the night from forest clearings, burnt out patches in the forest, or heather land. The goatsucker's voice resembles the mewing of a cat or the distant rattling of a motorcycle. The bird appears without any noise entirely. It is a small pigeon-size creature with long thin wings. Goatsuckers are not scared of people. They fly up close and whirl around a lonely wayfarer. Sometimes they hover in the air like a helicopter, fluttering their wings rapidly.

Goatsuckers are nocturnal birds. They stay somewhere in a forest clearing in the daytime, pressing tightly to the ground, but at twilight they fly up and start to search for insects which they catch on the wing. Impenetrable darkness blankets the forest at night in cloudy weather. It is a hard time for flying creatures. It is easy to get hurt badly in the darkness. And what about catching beetles and moths? Scientists suspect that Russian goatsuckers also employ echolocation. Nevertheless, it would be hard to say that they are as talented in this respect as their brothers in Venezuela.

SLOBBERERS

A traditional Chinese dinner consists of 150 dishes. It is no surprise that a traditional restaurant in Peking would never prepare dinner for more than two. The situation became more democratic after the overthrow of the Kuomintang regime and up to 10 people are served now.

Homo sapiens is an omnivorous being. However, the degree of omnivorousness differs widely with different peoples. Quite likely the Chinese hold the laurels and are the champions in this respect. What don't they eat! There is evidently not a single edible plant or animal that does not make its way onto a Chinese menu. This makes it possible for them to prepare an enormous variety of dishes. We are more conservative in Europe. To be frank, would you want to try a fried cat steak? How many of your friends would accept your invitation to dinner if they knew the main course would be cat baked in mayonnaise?

Most well-known delicacies, for example, live oysters, trepangs, green tortoise, and boa fillet are dishes often prepared for gourmets. The most exotic dish is probably the swift's nest soup. The birds mould their nests of their own saliva which rapidly hardens in air. These nests of "edible plastic" have made their builders—the salangan swifts famous throughout the world. No matter what kind of nesting material they use, for example, clay, down, bits of bark or grass, the swifts glue it with their own saliva. The feathers and down act as fillers in the nest, which is constructed mainly of saliva. Two species of salangans do not add anything at all to the saliva.

The salangans attach their nests to cliffs, very often in steep-walled canyons, grottoes and caves. Their "plastic" dwelling requires about 40 days to make and starts with a drawing. A bird selects a suitable steep wall, clings to it with its sharp claws and draws the outline of its future 5-6 cm long home with saliva. Saliva is smeared over the outline every day and the walls gradually grow outwards. Six weeks later it becomes possible to lay eggs in the nest.

The builders of the edible nests occur in Indochina, Indonesia, on islands in the Indian and Pacific Oceans. The native population have gathered swift nests from time immemorial. The nest gatherers go to the cliffs for their dangerous enterprise armed with long light bamboo ladders and

poles to knock off the nests. Salangans form tremendous colonies, numbering hundreds of thousands and even millions of pairs and the gatherers return home with loaded sacks on lucky days. Fresh nests, which have just been completed, are the most valuable. If the nest is taken away, the swift builds a second and even a third one, but these additional nests contain a great deal of dirt and are not valued very highly. They are cleaned together with the previous year's nests and then used for producing "dragon's teeth", which are large chips of shredded protein.

Evidently, even primitive men were fond of swift nests. Archaeologists have discovered ancient drawings on the cliffs on Kalimantan Island depicting men with long ladders resembling those used by nest gatherers today. Echolocation developed in salangans when colonies of the birds retreated into caves in an attempt to escape man. When they enter their caves, Ceylonese swifts begin to emit series of clicks at a rate of 5-10 per second. The clicks are short with a time interval of 2-6 mcs and are easily perceived by man because they are in the 4,000-5,000 Hz range. Java salangans generate location clicks but not so intensely, employing to this end low-frequency sounds up to 1,500 Hz.

Laboratory tests have confirmed that the clicks are location pulses. The swifts do not need them in bright light. The salangans possess good vision and pursue a diurnal way of life. The birds turn absolutely helpless when deprived simultaneously of vision and hearing. The salangans generate location pulses only in flight when flapping their wings. The birds do not emit sound when they are still. The echosonar of the swifts is not very good as they frequently collide with obstacles while flying around in a room with 8 mm plastic tubes or with slightly smaller metal rods. They barely notice wooden sticks 10 mm in diameter or 2 mm wire, as these reflect sound still worse.

It is quite noisy at a salangan breeding site. When it gets darker, the clicks merge into a dense crackle. The bird must

be able to discern the echo of its own clicks in this chaos of sound. Scientists still do not know exactly how they do it. A detailed analysis of the spectral composition of the clicks leads to assume that each bird possesses its own voice which is unlike the hundreds of thousands of voices of their kin. It is quite possible that they can recognize the echo of their own clicks like we discern the voice of a friend.

Echolocation is an inherited faculty, but it is only used by adults. Young nestlings are unable to produce clicks. Some time before leaving the nest, they begin to test their wings and voices. Having gained an idea of the surrounding area by sounding it out, a nestling takes off from the nest. This is a happy event for its parents, and it never returns. When the nestlings leave, the family breaks up. The young birds live on their own from the very beginning. It is unnecessary for them to learn to fly, catch insects, or use their location ability because they inherit all these faculties from their parents.

Other birds also apparently can echolocate, and snipes for example are believed to do so. When curlews fly in fog, they emit peculiar sounds that they never produce otherwise. It is assumed that the birds orient themselves by means of the reflected echoes.

It is quite possible that murres also possess the echolocation faculty. Many of them do not migrate to the South for the winter, and instead fly to the North where they spend the cold season near unfrozen polynyas. Evidently, the water is inhabited by luminescing unicell animals which flash like bright sparks illuminating the path of a fish when alarmed by motion in the water. If it is not the luminescing unicells, then what else but echolocation do murres use to find food in the pitch darkness?

Gulls too are thought to have location abilities. Ross's gulls are the loveliest of gulls, being inimitably beautiful. They winter somewhere over the ocean and zoologists have no idea how they live or find food in the darkness of the

polar night. No one has ever heard any gull sound reminiscent of location pulses, but this does not mean anything as there are many animals that use ultrasounds, which are inaudible to the human ear. Isn't it possible that Ross's gulls may do the same?

The ivory gull also has its habitat over Arctic ice fields. Location signals emitted by ivory gulls have never been recorded, but then no one has ever tried.

Mammals grew more sophisticated in echolocation as they evolved. It is well known that bats are the most sophisticated in this respect. Their sonar permits them to orient themselves in the pitch dark of the night, fly rapidly without colliding with anything, and detect tiny insects and catch them on the wing. But we'll not dwell on bats here because the echolocation faculties of these animals have been discussed elsewhere. This book is devoted to the inhabitants of the ocean. Let's deal with the echolocation facilities that aquatic animals have invented.

SQUEAKY BABIES

Three orders of mammals, namely, insectivores, chiropters and rodents unite an enormous number of small and tiny creatures. It can be stated without stretching the point too much that these three orders virtually comprise the whole class of mammals. All the lions, elephants, hippopotami and monkeys barely make up 10 % of all species.

The big animals, which we are more used to dealing with than with the small fry, employ quite low-frequency sounds, which can be easily picked up by human ear, for communicating and manifesting their emotions. Anything can serve as a signal, for example, howling, roaring, barking, neighing, grunting, a beaver flapping its tail against the water, the cracking of a porcupine's needles, the clatter of hoofs, or a gorilla beating its chest with its fists.

It is not accidental that the big animals have selected relatively low-frequency sounds for communication. Low-frequency sounds propagate in the air to considerably greater distances than do high-frequency ones. Only low-frequency sounds can cover the distances that elephants, lions, wolves or coyotes communicate over. Big animals inevitably had to develop an apparatus for generating sounds of the required range. Only some of these animals can generate high-frequency sounds as well. High-frequency whistling has been discovered only lately in some predators, ungulates and cetaceans. These sounds are not perceived by the human ear and until recently we never suspected their existence.

Small animals possess quite a different set of signals. Different species of mice, voles, and shrews do not need to send signals over great distances. Their world is rather small and they are not interested in anything beyond it. Hence, they have no need to generate low-frequency sounds. The "speech" of most small animals is dominated by high-frequency sounds up to 40 kHz, and some mice and shrews generate sounds up to 100 kHz. The use of high-frequency sounds provides them with certain advantages. Since they propagate only small distances and are intended only for the ears of their kin, the sounds will not attract the attention of predators. The closer the partner, the higher the frequency of the signals. The hearing of big predators is not adapted to perceive sounds with a frequency up to 100 kHz. Foxes, cats and owls locate their prey by the lower-frequency squeaks and whistles, and still more often by the low-frequency sounds of rustling grass and leaves as the small creatures move about.

The high-frequency sounds used by insectivores and rodents for communication are suitable for echolocation. As they employ their vocal apparatus, they cannot but notice the inevitable echo. It would be unnatural if this free present of nature remained unused. In some ancient time when bats had just learned to fly, they did not search for a new

method of orientating themselves in the world. They did not need to design a new apparatus for projecting their sounds. They possessed all the requisites of echolocation. They only needed to learn how to understand the information embedded in the echo and improve the design of their sonar. This they managed to do very well.

Thus, its has become known recently that most small insectivores and rodents can generate signals that are useful for echolocation. Nobody can state without special research whether they actually use these signals for echolocation, or whether they could actively echolocate space.

Shrews are the smallest of the mammals. The body of the smallest species is only 3.5 cm long, while it will never weigh more than 1.5 grams. Shrews resemble mice, but a carefull inspeciton will reveal many differences. The creatures have minute eyes, a long and mobile snout, velvety fur like that of a mole, and a long tail covered with hair, through which horn-like scales can be seen.

Shrews are widespread through nearly every continent, from the cold tundra in the North to the humid forests and deserts of the South. Shrews are not found only in Australia and on distant islands. Most shrews live on dry land, but some of them are semi-aquatic. They live in holes they have dug in the ground, or use holes made by other animals. They also dwell in rotten stumps or felled tree trunks. Shrews feed mainly on insects, varying their menu sometimes with worms and molluscs. The animals have very high metabolism. They are always hungry, managing to digest an enormous amount of food that is 2 to 4 times greater than their weight. The animals cannot endure more than 7-9 hours without feeding or else they perish. This is why they are considered neither diurnal nor nocturnal creatures; shrews have mini-days. A shrew looks for food until it is full, and then it returns home to digest the food and sleep a little. The moment its stomach is empty, the animal begins its next "day". White-toothed shrews have 120 "days" in

24 hours, meaning their "days" are 12 minutes long. The life-span of a shrew is between 14 and 18 months without any hibernation or interruption.

The Northern shrew has a litter of 4 to 8 young once or twice during the warm season of the year. The life of the female is very strained at this time. The young ones grow very quickly, suckling their milk intensely, and the mother must work like ten in search of food so as not to perish of starvation. A month later the young shrews grow to the size of their mother and become completely independent. Searching for food all the year round, shrews do a lot of good. Digging under the snow in the leaves covering the ground, shrews manage to rid the soil surface of insects during the winter.

An amazing phenomenon has been discovered in shrews, one that is unusual for all other species of mammals. The dimensions of the body, including those of the skull and brain, decrease in autumn in the young animals, while in spring their weight and volume return to normal.

The shrews include many surprising creatures. The hind legs of the water shrews, which are distributed from the shores of the Arctic Ocean to the Southern deserts, and those of the common and white-toothed shrews are covered at the edges with stiff hair. Web-footed shrews, as is indicated in the name, have webs between their toes. These are accessories for swimming. The lesser shrew, whose habitat is in Mexico and in the East of the USA, have apparently poisonous teeth which they use to store paralyzed worms and insects. The animals produce sounds that resemble the twittering of birds. The scale-footed shrew-mole in China and the common shrew in Ceylon have split noses with an individual snout for each nostril.

The dwarf white-toothed shrew, which is the tiniest one, lives in the Caucasus and in Central Asia. It is a graceful animal with a disproportionately elongated head. On average it weighs 1.5 grams. By comparison it is justifiable to

call the 12-15 cm tropical white-toothed shrew a giant, and the 18 cm white-toothed shrew in the Cameroons a goliath.

All shrews are considerate mothers. The Russian small white-toothed shrew has a litter of 5-10 young. When the babies grow up a little, the mother is unable to bring in enough food and she is forced to take her whole family with her when she goes out hunting. The babies hold on to one another in order not to get lost. The first one holds on to its mother by her thigh, the second holds on to the first, and the family caravan goes hunting in this manner. If the caravan chain breaks, the one that opened its jaws to lose hold of its brother desperately squeaks and the mother returns immediately.

When the shrews go hunting, they emit clear whistles from time to time, the whistle pitch sometimes reaching 100 kHz. Zoologists have become convinced that many animals generate sounds that they are unable to perceive themselves. It is extremely difficult to experiment with tiny shrews. Still, it has been shown that these animals, at any rate, perceive sounds up to 75 kHz.

Some scientists consider that shrews use echolocation, and one experiment tends to confirm this. Some 400 tiny bottles were placed at random on a small site. The slightest touch made the bottles fall. An animal was let into the area in complete darkness, and then the number of felled bottles was counted. Normal shrews and animals with shaved off vibrissae collided with the obstacles less than animals whose ears had been plugged.

Still more significant results have been gained in experiments in which the animals had to find by echolocation a platform which they could jump on to. The experiment was made as follows. The animal went through a thick plastic pipe and reached a round table. During the first experiments, which were performed with illumination, the platform that the animals had to jump over to was set at the same level as the table. When the animals got used to the

situation, the platform was gradually lowered and the experiments were carried out in complete darkness. The platform did not smell of anything and its position was continuously changed. Therefore, it could only be found by echolocation. When the animals solved the problem correctly and jumped down onto the platform, they could go down a special ladder into a chamber where there was food and water. If the animal made a mistake, it fell quite a distance to the floor and naturally received no reward. It had no other way out but to find the entrance into the plastic pipe, return to the round table and make a new attempt to find its way to the food.

After brief training the water short-tail and other shrews unerringly found a platform lowered by 5-11 cm. They detected the platform even at a distance of 25 cm but were afraid to jump down to it. The experimenters observed, using a night vision device, that the shrew fussed around the edge of the round table at the side of the platform, leaned over the edge but then returned to the centre of the table. Animals with plugged ears rarely solved the problem correctly. Evidently their hearing was absolutely necessary to detect the platform. A microphone mounted over the platform, indicated that the shrews generated in the darkness short and long high-frequency sound pulses. The rate of generation was not very rapid, 4-6 pulses a minute, and their snouts twitched all the time.

The method the shrews employ to operate their sonar under natural conditions is still unknown. Most of them live in forest litter where the entanglement of stalks, leaves and other forest debris ought to create such a complicated acoustic situations that it would seem unlikely that a sonar would be useful.

Soviet researchers consider that shrews do not employ even a crude echolocation, and explain their ability to avoid obstacles in the darkness and to find their way to the food by the fact that the smell of the shrews and that of human

hands was not removed sufficiently well from the bottles and the glass platform. The sense of smell is very good in the animals. The area of the olfactory epithelium exceeds 100 mm^2 in the tiny creature and a greater half of the big hemispheres of their brains analyse the olfactory information.

In experiments run by Soviet researchers shrews, running in narrow corridors, noticed at a distance of 20-25 cm that a passage was blocked. They turned and ran along unblocked passages. The ability to detect an unblocked passage could not be an innate one. The animals had to learn how to do this, and this does not indicate echolocation. Stopping at the crossing of two corridors in order to decide which way to go, a shrew will look around but not emit any sound. The researchers began to suspect that their devices were not sensitive enough for the weak sounds of the tiny animals. In order to make the experimental animals produce louder sounds, their ears were plugged. But all was in vain and no sound has been recorded.

Partitions with holes big enough for any shrew to go through freely were used to solve the problem of determining what assisted the shrews in noticing the partition, i.e. echolocation or olfaction. The smell of the partitions was the same as that of solid ones, but the echo would undoubtedly be different. However, the animals also ignored corridors with this sort of partition, and this indicates olfaction as the underlying mechanism of search. When the nostrils of the shrews were plugged and they could not use their sense of smell any more, the animals lost any ability to notice the partition from afar.

The second family of insectivores are tenrecs, who definitely possess the faculty of echolocation. There are about 30 species of tenrec. The majority of them actually feed on insects, but raise no objections against worms, molluscs and other tiny animals. The tenrecs have a sweet teeth and are fond of bananas and other sweet fruits. Water tenrecs are

vegetarians. Fish and insects are only seasonings to their main dishes. All these externally quite strange animals only live on Madagascar and some other islands to which they were specially introduced.

The appearance of the tenrecs is quite variable. The only common feature is the elongated snout and pointed mobile nose. The body of the small tenrecs is covered with soft short fur. They resemble shrews in appearance and mode of life. Rice tenrecs look like moles and follow an underground way of living. Some tenrecs remind opossums and hedgehogs, and the spines on their body are mixed with hairs that stand on end when the animal is frightened so that no one will wish to touch it. A tailless tenrec with its outspread spines and bristles seems to be twice the size it actually is. The beautiful fur of the motley tenrec is also mixed with many spines, which are quite numerous and long on the back of the head. When the animal is disturbed, a tuft of chaotically vibrating spines rises on its back, obviously inspiring certain respect in the predators.

The tenrecs have many surprising features that are still poorly investigated. The tailless tenrec aestivates for many months during the dry season of the year, and most tenrecs can pass into a state of torpor with a drop of the ambient temperature. During the rainy season the animals feed well, accumulate fat and endure easily during hungry times. As is the case with sheep with fatty tails, the tiniest tenrecs store the fat in the tail. The toes of the water tenrecs have webs that assist them in underwater swimming. The hedgehog tenrec exudes an offensive odour to scare off its enemies, but evidently man is the only enemy not scared away by the aroma. Hedgehog tenrecs are delicacies on Madagascar. Tenrecs are apparently the most fertile of mammals. The tailless tenrec sometimes litters up to 16 young, but they may sometimes be many more because the females have up to 24 mammary glands to feed offspring.

The American scientists who were lucky enough to do re-

search on these interesting animals repeated the experiments carried out with shrews. Many species of tenrecs have quite good sonars. Jumping down to a platform that was 11 cm lower, the animals missed it and fell to the floor only twice in ten cases. The experiments were carried out in complete darkness and the animals had no other way besides echolocation to detect the platform. If the animals' ears were plugged, they immediately lost their ability to fulfil the task, confirming once again that the tenrecs used echolocation to this end. It was possible even to record the sounds emitted by the animals. When the animals were still on the starting disk, the sounds they emitted were quite different. They generated high-frequency squeaking, snorting, gritting of teeth, twittering. However, the moment the animals started to search for the platform, and were aiming to jump down in the best way, they began to click with their tongues. The hedgehog tenrecs licked their lips, while the others simply opened and closed their mouths. The clicks were very short, being emitted in ones, twos or threes. The tenrec clicks had frequencies between 5 and 17 kHz. The animals produced from 8 to 22 clicks in one minute under unfamiliar conditions. Tenrecs can hear sounds from 0.2 to 60 kHz, but their optimum perception is in the range of 10-15 kHz, i.e. those used for the clicks.

The tenrecs were let in a labyrinth of corridors and they sensed the obstacles from afar if they were made of glass and metal, which are materials that reflect sounds well, but were confused if the obstacle was made of sound-absorbing material, acoustic rubber, or an object covered with velvet.

The experiments with massive glass disks were quite convincing. An animal was placed in a small cage in the centre of an arena. The cage had six doors which the tenrecs had been trained to open with their noses. A glass disk was suspended against each door at a distance of 20 cm. During the experiment 5 disks were suspended with their edge toward the animal and only one disk was turned to the ani-

mal with its flat surface. Naturally, all the 6 disks smelled similarly but the location pulses were reflected differently. It was only possible to determine in the dark the way the disks were suspended by echolocation. The tenrec had to open the door against the disk turned to it with its flat surface. It was rewarded in this case. If the animal made a mistake, it received an electric shock on the nose. The tenrecs made correct choices in 7-9 cases out of ten.

Scientists suspect other representatives of mammalian rodents have echolocation, i.e. the 1500 or so species of mouse. Most mice generate ultrasounds and high-frequency components up to 19-29 kHz have been recoded in the squeals of rats. This is evidently a communication signal because subordinate rats, expressing respect to their dictator, reply with a subordinate signal with a frequency up to 30 kHz. The offspring of yellow-necked and red-backed mice, spiny rat, and other mice demand attention, protection and maternal care using signals with frequencies of 60-80 kHz.

Undoubtedly, mice hear high-frequency sounds. A mother mouse hearing the call for help, which is not perceived by the human ear, rushes immediately to her offspring. The common hamster perceives sounds of up to 16 kHz, a black rat up to 20 kHz, a golden hamster up to 28 kHz, a yellow-necked mice up to 50 kHz, a baby-mouse and a Norway rat up to 60 kHz, a house mouse, a white rat and a guinea-pig up to 100 kHz.

Scientists are still guessing whether and when rodents use echolocation. Common and narrow-skulled voles easily learn in a laboratory how in the darkness to detect a platform down to which they have to jump, and can do so when the platform is 8-10 cm away. When the ears of the voles are plugged, they loose this location ability, while animals with cut off vibrissae continued to orient themselves perfectly in the darkness.

Albino rats, used widely in laboratories, have been trained to avoid corridors with a blind end. The observations in-

dicated that the rats did not emit any special sounds in this case, but they did snort, sneeze, chatter or gnash their teeth, or scratch the floor and walls of the corridor with their claws. Apparently, the echo of these sounds assisted the rats in finding the exit of the labyrinth. Deaf animals could not solve this problem. This capability of the albino rats is not unique and a human can learn how to echolocate within this scope. As they walk along a street, blind people tap the pavement in front of them with a stick not only to attract the attention of passers-by and to avoid collisions, but also because it enables them to keep a certain distance away from the walls of the houses and not to bump into large objects.

The family of dormice has been thoroughly studied. They resemble small squirrels and are covered with a fluffy fur. A long fluffy tail adds to the attire of the animal. The large expressive eyes make the little animal very attractive. Dormice are found in Europe, Asia and Africa, and the Soviet Union too. All dormice have forests as their habitat, with the exception of the mouse-like one. This mysterious animal lives in the Soviet deserts of Kopetdag.

Dormice are nocturnal animals, but it is quite a problem to see them even at night. These charming creatures love sleeping, for which reason in Russian they are called sleepers. During the day they keep in the hollows of trees and sleep untroubled, but when it becomes dark they wake up for 2-3 hours to stretch their legs and dine. At the beginning of the rainy autumn the dormice gather in friendly groups in warm hollows of trees or in underground shelters. They lay comfortably on their backs, blanket their bellies with their fluffy tail, fold their ears tightly, evidently to avoid draughts, and hibernate for 7-8 months until the beginning of the warm season.

It is not by mere chance that dormice have evoked interest. Undoubtedly, echolocation would not be an extra for these animals. It is not simple to jump from branch to

branch under the crown of a thick leaf-bearing forest in the pitch dark before a storm. And indeed when they climb tree trunks and jump, the animals generate ultrasounds. It has been possible to determine that dormice perceive sounds up to 50 kHz. But scientists differ about whether they use echolocation. American scientists studying the behaviour of edible dormice found that the animals could detect a thin pole in the dark that was 40 cm away from the platform holding the little creature. Soviet researchers have experimented on blinded tree, hazel and edible dormice. None of the animals could find a small wooden box for starlings even at a distance of 5 cm. The experimenters did not observe the blind animals generating any ultrasounds. It is a pity that these sweet creatures are unable to apply echoes.

It is quite evident that many animals from the largest to the smallest on our planet use echolocation.

PIONEERS IN HYDROACOUSTICS

Research on the underwater world for a long time lagged behind the research concerning land animals. Until recently we had only a vague idea of the life of aquatic animals. As usual, guess-work prevailed whenever true knowledge was lacking. All this refers also to fish. Academician I. P. Pavlov, who pioneered the study of the higher function of the brain, experimented almost solely on dogs. U. Frolov was the first of the great physiologist's colleagues to study fish. His articles, published about 40 years ago, demonstrated that fish are exceptionally primitive creatures. They do not even have sufficient memory to remember conditioned reflexes that they had been taught the previous day.

World War II halted all research on fish. Physiologists gradually accepted the erroneous views of Frolov. It is not surprising therefore that views on fish behaviour published 15 years later by a young researcher, N. Prazdnikova, encountered almost insuperable obstacles in the minds of other

scientists. She continued her work on fish brains and was so carried away by her discoveries that she at one time reported at scientific conferences that a decent carp was cleverer than a dog, although she was slightly embarrassed by her own words. It is true that she never repeated this view after she had begun studying dogs. Her work noticeably affected science and nobody today doubts that fish have memory and a certain wit.

Ideas about fish's sense of hearing have undergone a similar evolution. It was considered for a long time that these silent creatures in their "silent world" had no means of hearing and nothing to hear. Fish do not have the ears that decorate all mammals. Fish only have an internal ear and lack ear conches and the middle ear, which includes the tympanic membrane. The lack of the most important elements of a sound-recording system led to the idea that fish had not developed a sense of hearing and that sounds had no biological meaning for them.

The observations of fishermen and the results of simple experiments carried out by researchers 200-250 years ago, which demonstrated that fish could hear, were not taken into consideration for some reason. The experiments performed later were done quite unprofessionally and produced negative results. Evidently, the researchers that conducted them had not accounted for the considerable attenuation of the sound waves that occurs at a boundary between two media: when the waves go into the water from the air they are attenuated and as a result the fish could not hear the sounds used in the experiment. Only special experiments, carried out three to four decades ago restored the belief that fish can hear. They hear low sounds, from 50 to 5,000 Hz very well, and they hear as sensitively as mammals in the 500-1,000 Hz range.

In addition to an internal ear, fish also possess lateral line organs which perceive oscillations in water pressure and motion. Other aquatic animals, for example, lampreys and

the primitive amphibians, also possess these mechanical receptors. The ancient dwellers of the underwater world evidently had the sensitive cells of the lateral line, which contained a hair in each cell, the cells being arranged in longitudinal rows on the body surface. Lampreys and sticklebacks still have this sort of lateral line.

The lateral lines have been improved during the evolutionary process. The sensitive hair cells in chimaeras and lower sharks are embedded in grooves, while in the majority of fish today they are assembled in reniform groups and enclosed in canals that communicate with the environment through short wells. The canals are filled with mucus and the sensitive cell bodies fit into the walls of the canal and only the hair passes through the clearance. Two main canals run along the lateral surfaces of the body (hence the name), and divide into the supraorbital and infraorbital canals, and the mandibular and gill cover canals.

At the beginning of this century biologists understood the function of the lateral line organs. They had found that the hair cells reacted to the motion of the water. The water flow moves the mucus in the canals and, acting directly on the hairs, bend them. The hairs act as levers and stimulate the cells.

The lateral line organs are receptors of remote taction. They give the fish a sense of orientation in the water currents around them and warn them of approaching objects. Any creature moving near a fish causes at least a small movement of the water, thereby betraying their presence. Fishermen frequently catch predatory fish which have utterly no vision and yet they are still amazingly well-fed. Observation of blind pikes in an aquarium demonstrates that they respond to the approach of small fish and catch them without missing one. These fish pay no attention to dead and immobile fish. They detect anything moving and will attack a pencil, tea spoon, or the hand of the researcher with the same promptness. When a water jet is directed at a pike

using an underwater tube, the fish snaps its jaws at it. It is easy to see that information on the situation underwater is obtained by the predator by its lateral line organs. If the latter are carefully removed, a pike will notice neither a pencil nor a fat impudent carp. The sensitivity of a lateral line organ is phenomenal, and a fish can detect the movement of a glass hair 0.25 mm thick.

Tritons and other salamanders are predators. Their lateral lines are more developed on the head and assist them locate small animals in the water. The lateral lines of the African clawed toad are very sensitive, and it can notice the slightest movement in the water to locate tiny insects and worms 10 cm away.

Apparently, some of these animals employ water movement to communicate with each other. Courting tritons, flap their large tails vigorously. The violent dance of the water is as beautiful a love serenade for a female triton as a nightingale's song is for his modest grey wife. The males of the giant salamanders in North America make nests under stones and rocks in the autumn and attract the females ready for spawning by dancing. The Ranodon sibiricus in the mountain brooks of the Dzungar Alatau and the Far East clawed newt behave similarly. They attach a spermatophore (a small sac filled with spermatozoa) in a conspicious place and wait for the females, attracting them by their vigorous dancing, or in other words, by broadcasting using whirl pools. Once she has perceived this information, the female locates the spermatophore and attaches her roe sac.

It is not easy for fish to have offspring. The membranes of the spawn roe can be penetrated by the spermatozoa only 20-40 seconds after being exposed to the water. The behaviour of the male and female has to be strictly coordinated so that the roe can meet the spermatozoon in the little time allocated by nature, in the meantime the stream should not carry away the milt cloud. The exchange of information occurs via the agency of water jets. The males beat their tails

violently as they court the females, sending out a call for spawning. It is easy to imitate the commands of the male. By moving a glass stick near the tail of a stickleback, it is possible to make a mature female spawn. In spring female salmon without a partner sometimes makes a mistake and mistaking the vibrating oar of a canoe for the call of the male, responds by spawning.

Fish use their distant taction quite widely, and it is more important for them than vision. Fishermen know that when catching pike it does not matter whether their spoon-bait glitters in the water, the way it moves and vibrates is more important. Distant taction is equally important for both predatory fish and vegetarians. It warns the former of the approaching prey and the latter of an upcoming danger.

The recognition of mobile objects is passive location. Fish were the first animals to master active location. Scientists noticed a long time ago that blind fish could locate immobile objects, though only when they are large. The fish never collide with underwater rocks, or snags, and can probe both the bottom and the water surface. Blind fish are more careful in aquaria than fish with eyes, and avoid clashing against its glass walls. Evidently, vision is not always helpful for fish with eyes.

Active location is based on the phenomenon that any mobile object propagates oscillations in water. The pressure waves, propagating ahead of the moving fish, have a higher velocity than the fish proper. They reach any object en route before the fish and reflect from them, then being sensed by the hair cells on their lateral lines. Active location is important for deep-sea fish, which inhabit the eternal darkness of the ocean abyss, and this sense completely replaces vision. It is easy to analyse an environment in water at depths which contain no other objects but living creatures, and the validity of the information may be very high. It is not mere chance that deep-sea fish have developed better lateral lines than shallow-water species.

Using of reflected waves to orientate themselves was especially important for ancient aquatic animals. In the remote past there seem to have been few basins with clear water. Thus, lampreys and fish pioneered underwater echolocation, the first to apply to the assistance of the mischievous fairy who had been so severely punished by Hera.

Whales-Acousticians

THE VOICE OF THE OCEAN

The significance of acoustic underwater surveillance had been appreciated almost five centuries ago by Leonardo da Vinci. The Italian genius can be said to be the founder of this field of knowledge. He carried out the first experiments in the world in detecting enemy ships by listening to the underwater noise they generated and developed the first devices for hydroacoustic research.

Hydroacoustics was poorly developed before World War II, and biological acoustics had only just come into being. However, it was known that many inhabitants of the "silent world" were really quite noisy creatures but the sounds they emitted had not attracted anyone's attention. The use of hydroacoustics for military purposes was extremely limited, and the knowledge of biological noise turned out to be more important than it had been considered in peace time. The commands of the British and US Navies, who were fighting fierce battles with the Japanese, sensed this quite clearly. It was difficult to determine the origin of many of the noises in their hydrophones. The noises emitted by schools of fish were frequently thought to be the noise generated by ship propulsion machinery. There were many times when noisy fish schools were the cause of combat alarms! The false alarms most frequently occurred at dusk

when certain fish came up from the depths and approached the coast in large schools. A big and friendly school emits such a cacophony of sounds that even the noise generated by vessels is inaudible. No one had even suspected that the "silent" fish could be the source of such a rattle and clatter. The sonar operators were certain that they had encountered the enemy. The commotion at Chesapeake Bay* in the spring of 1942 became widely known. The hydroacousticians of the coast guard had detected very loud underwater noise and were convinced that only the engines of many submarines could generate such an acoustic storm. All the detachments were alerted for a German landing force. There was no landing forces, nor could the US military intelligence discover a single enemy vessel or a submarine.

The allies had sufficient reasons for increased suspicion. In the spring of 1942 the German and Japanese submarines roamed everywhere. They went to sea in groups, which the Germans called "wolf packs". The submarines of Grand Admiral Denitz were equipped with snorkels—long pipes with a head at the end to draw in air and exhaust gas. The snorkel extended above the surface and the submarine could remain submerged a small depth and be invisible even during the daytime. The coast guard system was under constant strain because they were sure that with the fall of night they could be attacked at any moment by enemy destroyers or submarines. The Germans did in fact carry out daring raids. The largest ship in the British Navy—the battle-ship "Royal Oak"—met a tragic end. It was sunk by a German submarine in its own base, the holy of holies of the British Navy, Scapa Flow. The submarine's acousticians helped the raid succeed. Having carefully approached the entrance to the harbour, the submarine waited until a British transport vessel returned to the base. Then by listening to the noise of its engines and repeating its every manoeuvre, the sub-

* Chesapeake Bay is on the west coast of the USA.

marine entered the harbour avoiding the mines, launched its torpedoes and departed for the open sea leaving the British totally perplexed.

Acousticians were rarely able to determine the real cause of false alarms. Suspicion, which is inevitable in these cases, gave rise to legends that the Japanese had managed to make their engines sound like fish schools. This legend may well be substantially true. At the beginning of the war the Japanese suffered greatly owing to their lack of knowledge of biological underwater noise. We'll never learn how many times fish schools forced Japanese submarines to lie quietly on the bottom, because they thought they had heard the noise generated by the screws of an approaching Allied fleet. Japanese scientists carried out bioacoustical research from the very beginning of the war under Prof. A. Hayama, but tangible results were only gained in 1944. Records of biological noise were given to submarine designers and evidently Japanese scientists really did attempt acoustical mimicry, adjusting the noise of their engines to make it resemble fish school noise. It is possible that this work may only have been successful for the "kaiten" ("the road to paradise") apparatus, which was a manned torpedo. At any rate, several minisubmarines charged with explosives and each carrying a condemned man aboard managed to break through to the moorings at the Palau and Ulithi Islands.

The German command was also worried that their submarines generated too much noise. Underwater noise was studied intensely in Germany even during the last months of the war. Submarines of the "Sea hound" series generated low noise and were designed in cooperation with acousticians. Each of the submarines in this series was tested after launch for hydroacoustic certification at one of the marine research bases in the Baltic Sea. The Allied countries in turn improved their acoustic surveillance. Various Soviet and Allied vessels were equipped with hydroacoustic devices that were superb in quality for the time. This undoubt-

only had results for military actions. Japan had lost almost all of its submarine fleet before the end of the war. Biologists assisted the military in organizing their sonar service. And when the guns stopped shooting, their research continued with purely scientific aims. A new science, namely, biohydroacoustics originated at the boundaries of the two disciplines.

Many different fish species in the tropical and temperate latitudes emit quite loud noises, the singing fish being the best known. These are small creatures about 25-35 cm long and they live near the American coast in the Pacific and Atlantic Oceans. The fish have been called singing because of their peculiar colouration and luminescing spots that are arranged in strict rows, like bright buttons on a uniform.

The fish attract attention as they reproduce because they spawn near the shore, in river mouths and in shallow sea bays. The females swim away after spawning and the males remain to defend the roe. They drone on continuously, evidently scaring away their enemies. During the war the simultaneous droning of thousands of singing fish was identified as the approach of a "wolf pack".

The toadfish is also quite noisy. Its voice resembles at a distance the hoarse grumbling and whistles of faraway ships. The sounds are emitted in series at a rate of two-three times a minute. Anyone unfamiliar with this phenomenon would think that a ship is calling for help. The sounds are so strong that close up they sound like a train or a pneumatic drill. Measurements indicate that the intensity of a toadfish scream exceeds 100 db. Sometimes they can cause painful sensations in the listener. The sound generator is the swimming bladder, which resembles the stylized image of the heart.

Toadfish like to stay at home. Each owns a certain territory where it dwells permanently. Reproduction begins in the first half of the summer. The female spawns a group of large roe and the considerate father defends it for about three

weeks until larvae that look like tadpoles appear. The whistles of the fish are warning that the area is defended. Toadfish meeting, as listened to through sonar headphones could have caused the panics among the naval intelligence officers.

Scientists could not determine all the culprits of the false alarms during the war but the Atlantic croaker was caught red-handed. It sowed panic all along the American coast for croakers are widespread large fish. Today about 150 different species of croakers are known. They are bottom-living fish that swim in large schools near rocks, caves and rock streams, where they usually hide in the day-time. When dusk falls, the fish leave their refuge, swim up from the depths, and enter bays and river mouths. They approach the coast in noisy schools. Evidently, they must encounter many things en route that they consider necessary to discuss. Very few land animals allow themselves such a row. These fish are extremely noisy when spawning starts and it can be assumed that the coast guards were alerted by the love controversies of croakers.

Croakers, like toadfish, emit sounds by contracting muscles that surround their swimming bladders, which function as resonators. They pay a high price for their unreasonably noisy behaviour. The concerts of the "sea drummers" that inhabit the Atlantic Ocean help fishermen in locating their schools. Another croaker species in the Mediterranean assembles in large groups and pierces the nocturnal tranquility by melancholic groans that are endlessly repeated in a certain rhythm. The groans of the croakers permit fishermen to trace and enclose the school in nets.

The list of fish capable of emitting loud sounds is quite numerous today. Undoubtedly, the ocean will reveal other new bawlers, whose voices may have fused with the row at croaker choral practice, perhaps they seem hoarse owing to their long vocal exercises, that once alerted the acousticians of the coast guard observation posts during the war. A cluster of shrimps can generate a considerable amount of noise.

It is simply unimaginable that such small and quiet creatures can be the source of such a cacophony. The storm of clicks, like that produced by spilling a sack of dry peas onto an asphalt road, is accompanied by squeaking and ringing. In general, the sea is inhabited by many noisy creatures that organize stormy meetings, agitated demonstrations, and concerts of choral signing at certain periods of their life.

Melancholic groans, heavy breathing, piercing squeals also once perplexed the acoustic intelligence service. These were the groans of the humpback whales and were frequently recorded by observers on the Hawaiian Islands. The source of this noise is well-known today, but imagine what it was like to hear it during the war. It should be borne in mind that neither an officer's uniform, nor an engineer's diploma relieve of believing in witchcraft that is quite popular and widespread in the United States.

The ancient Greeks knew that dolphins and other cetaceans could emit most different sounds. But did anybody in the higher ranks of the Navy know it? When a combat alarm was sounded, nobody imagined that these giants of the sea were the ones to blame.

DOLPHIN PRIMER

The first seaquarium in the world was "The Sea Studio" and was opened almost 40 years ago in the small town of Saint Augustin in Florida. At first it was populated with giant clams *Tridacna Gigas L.*, which grew to 1.4 m in length and weighed up to 200 kg, common and spiny lobsters, crabs, turtles, and tropical fish in a bright and whimsical array. Some time later, and not without a certain hesitation (because there was no certainty that the animals would interest the visitors) Atlantic bottle-nosed dolphins were introduced to the seaquarium. Since that time dolphines have been the most permanent and attractive inhabitants of the

seaquarium. Trained dolphins were demonstrated in the Soviet Union as far back as 1936 in the "Adygey" mobile circus which performed in Turkmenia. For some reason dolphins did not evoke any scientific interest at that time.

Bottle-nosed dolphins inhabit all the oceans but prefer coastal waters to the open seas. Obviously, we know these dolphins better than the other 50 species owing to their constant appearance near our coasts. They can become attached to man just like dogs and these dolphins can be trusted, which cannot be said about monkeys whose intelligence is so frequently compared with that of dolphins.

Bottle-nosed dolphins are not the smallest of the toothed whales though they are certainly not giants. The steep forehead and head are not separated from the body. The big kind eyes and the constantly smiling mouth express so vividly their friendliness that in a very short time one becomes used to the rather long jaws with almost a hundred big teeth. The animals are extremely attentive and careful with people. Even a romping young dolphin that jumps a metre high above the water surface to grab a fish from your hands will do it so carefully that it will neither touch your fingers with its teeth, nor even touch you with its wet nose.

Bottle-nosed dolphins are quite sociable creatures and live in schools. The school is a complex structure and contains small family groups that are headed by female-mothers. It was observed in dolphinariums that there is a mutual affection between mother and offspring for many years even when they were separated from each other for a long time and have become members of different communities.

The young are born in summer. One or two experienced females assist the labour. At first they support the mother on the surface and then they help the young one to come up to the surface and inhale air for the first time. The delivery process proceeds rapidly. The young appears with its tail first and very soon begins to swim independently. However, the voluntary assistants watch him carefully and are

ready to rush to the rescue at any moment. The selfless mutual assistance of the dolphins, which has become so widely known, is apparently rendered between animals that know one another well. If a female begins to give birth to a young one and she has only recently been caught and had not enough time to make friends with the other inhabitants of the basin, the other inhabitants become extremely excited but will not assist their new acquaintance.

The mother has a great deal of trouble at the beginning. The young one is permanently hungry. The female feeds it every 10-30 minutes "lying" on her side so that it will be more comfortable for the baby, who begins to include fish in its diet only after 3-4 months. The baby is very weak and the mother takes it in tow so that it will not lag behind. The baby keeps close to its mother all the time, somewhere below or aside her tail, and repeats all her movements. It would seem from afar that the baby holds on to its mother. The little one spends considerably less energy this way. Evidently, the turbulence that is generated around a swimming animal "sticks" in water layers to the mother's body and it draws in some of the flow stream, which in turn pulls the baby along. Trainers know from their own experience that it is extremely easy to swim pressing close to the dolphin. You will immediately lag behind these very fast animals the moment you move away from its body.

Dolphins hunt in groups. At first they send out scouts, and when one locates a fish school, it calls its own school to have lunch. Using sudden forays into the school the animals drive a single large fish to the shore and grab it there. The fish school is surrounded, driven into a heap, and the dolphins swim around in a ring and pick out choice bits.

It is hard to say exactly who was the first to suspect dolphins used echolocation. The director of the "Sea Studio" A. Maxbrand wrote in his diaries that the animals orient themselves perfectly well even in complete darkness and quite easily find fish that had been thrown to them. Max-

brand once supervised the capture of dolphins in a narrow sea bay the animals sometimes visited. When the school entered the bay, its mouth was closed with a trap made of strong nets. However, this manoeuvre did not work because it was impossible to drive the animals any closer to the nets than 30 metres. The dolphins could not see the nets at this distance and so their behaviour suggested to Maxbrand that they used echolocation. He thought of a method to outwit the animals and made a net with a larger meshes. The echo was weaker and scared by the pursuit and losing their heads because of fright, the dolphins paid no attention to the weak echo reflected from the nets and were successfully caught.

Maxbrand's diaries became known to the public only after he died. U. Shevill and U. Kellog were the first to confirm experimentally that the cetaceans used echolocation. An experiment with dolphins is extremely expensive because it entails catching, keeping, and training the animals. Hence, Shevill and his wife Barbara bought a pensioner from the seaquarium for their experiments, i.e. an animal that was well trained but too old to perform the complicated circus tricks.

The scientists made a pond on the sea shore for their experiments, its location making it easier to change the water in it. The conditions for investigating echolocation were ideal. It was not necessary to invent anything to deprive the dolphin of the possibility of using its vision because the water in the pond was always turbid. During the experiments the pond was partitioned into two halves by a net with a small passage at the side so that the animal could swim from one half into another. The scientists threw fish into the water and the dolphin, being deprived of vision, had to guess on which side of the net it was. The animal received the fish only if it guessed correctly from the very beginning. The task was simple and was always solved. The scientists learned that the animal emitted squeaking sounds

when searching for the fish and the use of echolocation or sonar in dolphins was established.

Owing to the lucky hands of Shevill the strikingly attractive bottle-nosed dolphins have become the favourite object of research and attempts have been made to use them in the open seas.

Many books have been published on dolphins over the last few years. Usually the authors of the popular science books describe the innate love of dolphins for people. The friendliness of dolphins is exaggerated, but, several cases are known when free animals have contacted people. But these are exceptions and not a rule. Several years ago a young male named Gals was used to make a popular-scientific film called "The Language of Animals". A storm destroyed the pond where it was held and the animal was suddenly turned free. Some time later it appeared on beaches near Yevpatoria in the Crimea. Gals swam into the shallow water and bravely approached the bathers, rubbing against their feet, permitting them to stroke it and gladly letting children ride on its back. The dolphin appeared so regularly that it became necessary to start selling fresh fish to those who wished to treat the visiting sea guest.

It is widely known today that bottle-nosed dolphins can be tamed but it would be wrong to believe that recently caught dolphins try to communicate with people straight away. Anyone who deals with them regularly knows how much effort is required to make a new animal placed in a pool stop quivering from the touch of a human hand. Quite frequently the animals stay hungry for several weeks, will not approach the walls of the pool, and will be scared of any floating object. It is especially difficult to tame old animals that have had a leading position in the hierarchy of a school. If such a dolphin is placed in a spacious pool and attempts are made to establish contact with it without entering the water, years may pass by with no rapprochement.

I once dealt with a large male. It remained in captivity for 6 months during which every attempt to adapt it to experiment was a failure. During the day, while people were scurrying around, the dolphin stayed in the middle of the pond and always in the same pose, i.e. with its nose toward some scaffolding. This position made it possible for the animal to watch the people. It could not see the remote end of the pond, which was quite far behind it and from where people could not endanger it, so the dolphin reconciled itself with the absence of information about its rear.

In spite of its long life in captivity, the animal would not feed in the presence of people. Only a considerable decrease in its daily ration and after several weeks spent on making the dolphin used to the permanent presence of people nearby changed the situation; the animal would sometimes swallow a fish thrown under its nose. Even several months later the dolphin would not take fish at the walls or corners of the pond, and it never touched fish that sank 1 or 1.5 metres below the water surface. The animal avoided diving for a long time, instinctively feeling that it was more reasonable to keep the people within sight.

Unsociable dolphins are not a rarity. In order to assist the animal in overcoming its fear of men the animal is placed for a long time in a small pool, where no matter what it wishes it cannot but contact its obtrusive trainer. Once it is convinced after some time that communication with man is not dangerous, the animal changes its attitude toward the clumsy two-legged creature that comes in the morning with a pail of fish. Only then will a dolphin turn into the sweet creature whose society always brings in profound pleasure. The dolphin now wishes to communicate with people. When you want to leave, the animal will perform all the tricks it has learned in captivity to keep you in the pond a little longer. It will juggle with a jelly-fish, jump out of the water and dive back without a splash, or vice versa, plunge into the water with a terrific noise and a wide smile,

grunt or emit other sounds, and if nothing works, it will drench you with a water splash.

Tame dolphins are easily trained. They can be let out into sea without any hesitation and they will never go away. Even if they do prefer to stay free, they will always visit you from time to time, nor will they do so with the aim of being treated to free fish. Dolphins are slaves of their habits. Having switched back to feeding on live fish, they will ignore frozen fish. The dolphins return with the sole desire to communicate with people. Undoubtedly this testifies to their high intellect.

The psychics of dolphins is quite peculiar. Common conditioned reflexes, which can be inculcated in a dog in twenty to thirty minutes, develop rather slowly in dolphins and only become stable after four to six weeks of systematic training. Not all animals can even learn a simple skill, for example, depressing a lever with its beak. They master new tricks more easily by imitating trained dolphins. It might seem extremely silly, but recently caught dolphins cannot run away from a netted pond, the walls of which barely extend above the water's surface. They must be taught to do so! And yet jumping out of the water to a 1 metre or so is a mere game for these animals.

Other peculiarities in the behaviour of the dolphins, on the contrary, show they have quite profound mental abilities. They possess an innate passion for imitation, learning balancing tricks from each other. Their love for games also confirms their high intellect. The animals play selflessly, balancing balls, throwing articles up into the air and then catch them again, participating in group games. A game may continue the whole day in a pond with several dolphins, and only lunch will put an end to their merriment.

There are some well-known cases when dolphins have saved drowning people or protected bathers from sharks. This is also considered to be a manifestation of their intellect. However, it should be said that mutual assistance between

the members of a school is based on inborn reflexes. They are programmed genetically. However, in certain cases the assistance they render a man is more the consequence of blind instinct than intelligence.

Another interesting feature in the behaviour of dolphins is the absence of aggressiveness toward human beings. This is not a testimony to the innate kindness of dolphins toward people. If an unknown human or anyone who is unpleasant to them falls into the pond, the dolphins can express their negative attitude toward him by swimming up close and defecating. It is quite clear that they do not wish for his society. The taming of the animals is neither a positive nor negative indication of their intellect. The absence of aggressiveness is evidently not a manifestation of intelligence but an instinct inherited from their ancestors. When the ancestors of the modern cetaceans made their first attempts a hundred million years ago to enter the oceans, they met no dangerous enemies there, and the instinct of aggressiveness was extinguished. A hundred million years is quite enough time to get rid of any negative habit.

BABY-WHALES

The number of whales in the oceans of the world has become noticeably smaller over the last two decades. People who work on the dry land have little chance to meet a real giant. A long journey is necessary to learn their mode of life. I was lucky to meet a live whale for the first time on the shore. It happened in the Crimea, in the shaded alley of a biological station. A young man was walking toward me along a shelly path, holding a whale in his outstretched arms like a man who has just became a father with his baby in his arms. The whale looked at me with its small weak-sighted eyes and trembled at every step. It was a real live whale, but only a baby-whale. I called it so not because it was newly born for the babies of big whales that have just

been born are measured in metres and can weigh several tons. The young man I was meeting was carrying a representative of the smallest of the cetaceans—an Azov dolphin, or to be in accordance with the zoological classification it ought to be called a common porpoise. These animals are quite widespread. Unlike most dolphins, they are not afraid of cold weather. The common porpoise is found in the coastal waters of Europe, Asia and America, from the Barents Sea to Dakar, and it enters all the Soviet inland seas, namely the Black, White and Baltic Seas.

This is the smallest species of porpoise. Their average weight is slightly above 30 kg, and the females are larger than the males. The short head of the animal has a gently sloping forehead ending with a turned-up nose; they have no clear beak. The animal's back is the same colour as the wet inner tube of an automobile wheel—from dark-grey to black, while the belly is much lighter.

Porpoises live in small families, though large schools do appear around big schools of fish. In summer the porpoises migrate to the northern regions of the Black Sea, appear near the Crimean coast, and go to fatten in the Azov Sea. They can stay submerged for only 6-7 minutes and will not dive deep. Their diet consists of slowly swimming fish—bullheads and alike. They suck in small fish, for example the khamsa, through a slightly open mouth directly from the school. They are real workers because they must catch 4-5 kg of fish, or 1-2 kg more in the cold season in order to be full.

Many common porpoises inhabit the Black Sea but they are not the dolphins that we can admire from the deck of a ship or the embankment at Yalta in the Crimea. They can not jump out of the water and , though they surface frequently to breathe, they do so quickly and in an offhand manner without stopping moving forward even for a second. The head of the animal hardly appears above the water surface and it is difficult to notice a school of porpoises.

A porpoise could not be called an intelligent animal. Some trainers say that they cannot be trained though it is not really possible to agree with this categorical statement. Undoubtedly, porpoises are less sociable than bottle-nosed dolphins. They do not express any special interest in men or, at least, are not capable of demonstrating it.

The monotony of their behaviour indicates that they may be extremely primitive. Porpoises spend their whole life in motion and when they are let into a pond they swim in rings day and night. They cannot sleep suspended at the surface like bottle-nosed dolphins do but they can be taught many things. When this tiny whale is in captivity in the company of bottle-nosed dolphins, it can learn in several days how the dolphins sleep at the surface or jump out of the water.

Soviet researchers in echolocation do not feel too much respect for these porpoises. Even the most enthusiastic researchers would not regard them to be our equal in intelligence. Nevertheless, porpoises have played a significant role in the investigation of the faculty of marine mammals to probe the space acoustically. One experiment is not enough in science, it must be confirmed. Kellog's team carried out its research simultaneously with the Shevill couple. They kept porpoises in a small pond on the shore of the Gulf of Mexico. Metal rods were driven into the bottom of the pond and the water was periodically stirred so that the animals could not see the rods. The porpoises swam between the rods in the absolutely turbid water without touching them even with their tails.

The researchers were still full of doubts. Maybe the vision of the porpoises was so perfect that the turbid water was no obstacle? The experiments were continued. The pond was divided into two parts by a net with two passages so that the animals could swim from one compartment to another. The signal for going to the adjoining compartment was the splash of a fish thrown into the water. The scientists closed

one of the passages during the experiment with a piece of plexiglass so that it was impossible to see the partition even in clear water. The animals were never fooled and if both passages were closed, they would not even attempt to go to the adjoining compartment. When one of the passages was free, the animals took off from any distance directly in its direction. No observations were recorded of the porpoise knocking its beak against the invisible obstacle or even approaching it by mistake. In another series of experiments different objects were thrown into the pond. The objects were thrown in from behind the animal so that the porpoises could not see what fell into the water. The curious animals immediately turned toward the splash, emitted a series of clicks and, locating the sinking object with their sonar, took off in pursuit. The sonar of the porpoises was so sensitive that they could immediately find a glass bead or a tiny lead shot in turbid water. It was impossible to trick the animals. If half a cup of water was spilled into the pond, the animals immediately turned toward the splash, searched with their sonar and then concerned themselves with their own business. They were so confident in their sonar that they never swam over to check whether anything interesting had appeared in the pond.

The diet of the cetaceans has assisted researchers studying the location faculties of the animals. The porpoises are very conservative creatures. If they are used to a certain food, it is very hard for them to switch over to another one. They frequently stay hungry for long periods of time but refuse categorically to dine if the diet is unfamiliar. At first the researchers were unaware of this and, what is more important, did not wish to consider it, believing that the same food would cause irreparable harm to their health. Kellog team sometimes bought fish of different species for his experimental animals in order to diversify their diet. The researchers were surprised not only by the rejection of the new treatment by the porpoises but also by their ability to

differentiate two similarly sized and similarly shaped and coloured fish in turbid water without even approaching them closely. They ate some fish readily, but were entirely indifferent to others. Kellog also had the possibility to observe the fish at close hand but he couldn't learn immediately the difference between them. Kellog's experiments indicated that echolocation is widespread among cetaceans because his porpoises are not closely related to the bottle-nosed dolphins that the Shevills experimented with.

Even after the experiments of Kellog there were still many sceptics who would not believe in the existence of hydroecholocation.

The problem of echolocation was solved finally after experiments on animals that were "blinded" using rubber hemispheres placed over their eyes. The behaviour of the porpoise did not change though the animal could not see anything at all. The porpoise oriented itself perfectly well, found its food no matter the small size of the pieces of fish dropped into the pond, located objects thrown into the water, and performed readily and accurately all the tricks it had been trained to do. The scientific world then finally believed in the echolocation faculty of the animals.

The bottle-nosed dolphins had made scientists suspect that cetaceans could echolocate. The experiments with porpoises broke down totally the peace of dozens of engineers and hydroacousticians who wanted to learn how a dolphin's sonar is designed. This was the beginning of a long series of experiments. Bottle-nosed dolphins and porpoises are the permanent objects of these experiments.

ECCENTRICS

An expedition of American scientists arrived in November 1968 in a small settlement named Sakkura near the Indus River. They had come intending to study the Gangetic blind dolphin. The local inhabitants knew these animals well and

frequently hunted them because dolphin's meat was considered quite tasty. However, it was one matter to hunt a well-fed animal for supper, and quite another issue to catch it alive without inflicting any injury. No one had ever done that in West Pakistan. Nevertheless, after several nights the hunters managed to catch three females lured by live catfish bait. The dolphins were small animals, the smallest one being 107 cm long and weighing only 19.5 kg. The largest was 121 cm long and weighed almost 26 kg.

The animals were put into a pond so that they could rest before their long journey. The dolphins swam at first near the surface as if they were storing up energy, breathed deeply, let out bubbles, and then they began to dive and surfaced only to breathe. The researchers got busy with other matters. The water in the pond was just as turbid as in the Indus River and it was impossible to see what the dolphins were doing in the deep water.

The animals were flown to Karachi the next day where the organisers had planned to stay for two days for an intermediate rest. The animals were placed in a pond with specially prepared clear water. Apparently this was the first time that people had ever been able to observe the behaviour of this sort of freshwater whales. The scientists were amazed: underwater the dolphins only swam on their sides! They either kept near the bottom touching it with their flippers or they rushed over the bottom only 2-3 cm above it. The heads of the animals were slightly lowered and the tails were lifted. In general, the dolphins swam parallel to the bottom with their bodies inclined 10° to the horizontal! Their movements were distinctly asymmetric: the largest animal only swam on its left side and always clockwise, while the other two dolphins swam on their right sides and only counterclockwise. An extremely strange asymmetry!

After their rest the journey was continued and the dolphins arrived in Tokyo on the same day. Another rest followed and then the animals made the flight over the last leg

to San Francisco. The animals had been flown almost 18,000 km in five days, giving a lot of trouble to those accompanying them. The animals refused to eat. No matter what sort of fish they were given, the dolphins paid no attention. The scientists even purchased freshly caught fish, but their prisoners had no appetite. Finally, they were force-fed, but to everyone's regret these dolphins did not live very long in captivity. The animals caught pneumonia and they couldn't be saved. The first dolphin had survived for about a month, and the last one died on the 44th day. Though their acquaintance with these Indian creatures was brief, the scientists were still able to learn that Gangetic dolphins had active sonar. Despite their lack of vision, they could orientate themselves well and never collided with underwater objects.

Unlike other cetaceans, which use echolocation only in the darkness, under complicated conditions, or in search of small objects, Gangetic dolphins generate location pulses continuously, about 20-50 pulses per second. This blind animal has no other means to detect an obstacle and it has to "feel" the environment involuntarily. The sounds they send as location pulses are in the frequency range of 15-60 kHz. They are similar in this respect to the location pulses of other freshwater dolphins.

The Indian dolphin has three close relatives, the Chinese lake dolphin, the La Plata dolphin, and the Amazon river dolphin. Freshwater dolphins belong to the oldest family of toothed whales. They all have a very mobile head, and long extended beak covered with stiff tactile hairs at the end. These evidently assist them in digging worms and molluscs out of bottom silt.

The Chinese dolphin has been the least studied one. It is found only in one place, the Duntinkhu Lake. It is a quite big river whale, reaching 2 m in length and weighing up to 120 kg. Its body and head are grey, while its belly and chest are somewhat lighter, as is common with most dol-

phins. The blowhole, like that of all other dolphins, is located on the top of its head and a little to the left. Here again we encounter asymmetry but its cause is still unclear.

Duntinkhu Lake is not located in a remote part of China but in a densely populated district. Nevertheless, scientists only learned of the existence of this lake dolphin only in 1918. It lives in small herds of between 3 and 12 dolphins, feeding mainly on bottom living animals. Eels and sheatfish are the main species found in the stomachs of these dolphins and both species bury themselves in the silt, where the dolphins evidently find them. Before swallowing molluscs and crustacea the dolphins chew them a little, crushing their lime shells or chitinous carapace.

The Amazon river dolphins are even larger—up to 2.5 m long and weighing up to 130 kg. Their light-blue backs and the small fountains above their heads when they breathe out are familiar sights in many of the large rivers of South America, from their mouth to far into the continent. When the tropical rainy season comes and the rivers flood the surrounding jungles for hundreds of kilometres, the dolphins move through the forest from the Amazon to the Orinoco River, and back. These dolphins feed only on fish nor do they shrink from paranha—the terror of the Amazon River. A dolphin uses its slightly down-bent long beak, which is covered with tactile hair, to pick freshwater crabs from the bottom. It then bites and swallows them. The long rows of slightly wrinkled teeth of these dolphins have two purposes: the front ones hold the catch and the rear ones chew it.

Amazon river dolphins became the favourites of zoos and parks in recent years. They have charmed the visitors and are now brought to areas that are quite remote from the sea. It is quite a problem to keep the animals. The dolphins are also kept in seaquaria. They are tamed very easily and approach readily their trainers and visitors in zoos. When free, they very rarely jump out or even emerge from the water. The animals must be specially trained to do so when

they are in captivity. The dolphins see quite well but still they have a good sonar, which they use while hunting, even when doing so in clear water.

The La Plata dolphins are the smallest of freshwater whales. They are never more than 2 m long, while their maximum weight is 35 kg. This animal has more teeth than any other mammal inhabiting our planet: the mouth of the La Plata dolphin contains 240 teeth. These little whales are found in the estuary of the La Plata River and in the coastal waters of the Atlantic Ocean. Zoologists suspect that the dolphins migrate closer to the equator with the approach of the cold season but they have no exact data on this migration. In general, very little is known about La Plata dolphins. The animals never gather in schools and will not approach ships or boats. It is true that they are frequently caught in fishing nets, but a dead whale can never tell a researcher much about its mode of life.

About 1,500 La Plata dolphins are caught annually near the shores of Uruguay. The fishermen use their meat as a bait for catching sharks. Dolphins of other species are never found in nets so frequently as their sonars can locate the perfidious trap before it is too late. It seemed therefore that La Plata dolphins could not echolocate. This assumption was confirmed by the fact that their stomachs mainly contained large fish that could fluoresce and that emit continuously quite loud sounds. Such fish can even be caught during the night without echolocation.

A team of French and Uruguay scientists have carried out a special investigation to determine how these whales orientate themselves. The team lived on the ocean coast in a small Uruguay village named Punta-del-Diabolo. Several scientists spent the day in the open sea with local fishermen, looking carefully at the water surface and listening to the underwater sounds using hydrophones.

Silence reigned in coastal waters in the morning, but some grunting and quacking was recorded by 10-11 o'clock,

The singing fish were waking up. At noon the grunting was more frequent and by 3-4 o'clock in the afternoon it turned into a chorus. The underwater sounds were carefully recorded and, listening to the records made during the day, the scientists were sometimes amazed to hear echolocation clicks of some dolphins, though they never saw the animals near the boat.

It is extremely difficult to see a La Plata dolphin in the open sea. Its dorsal fin is not high enough to extend from the water when the animal swims near the surface. It never jumps out of the water, and its forehead and blowhole raise only 2-3 seconds above the water surface. During the two months of work the scientists were only six times lucky to see the little whales and only once they heard the sounds the animals emitted. This happened once when two dolphins swam up 25 m from the boat four times and lifted for 4-6 seconds above the water surface. No other dolphins had appeared that day in the given area and the scientists decided that the sounds they recorded belonged only to these little whales.

The clicks recorded by the researchers resembled those emitted by other dolphins. The low-frequency sounds were below 3 kHz, the medium-frequency ones were in the 10-16 kHz range, and the high-frequency sounds reached 18-24 kHz. The duration of the clicks varied from 1.5 to 5.0 mcs.

Thus, the parameters of the La Plata dolphin's sonar is not inferior to those of the other cetaceans. Apparently, the animals are caught in the fishing nets because they use the sonar rarely. The La Plata dolphin, evidently, does not whistle to communicate like the other cetaceans. They are not sociable creatures and do not need to get involved in stormy expressions of their feelings. In addition, they avoid attracting anyone's attention.

The winter in the Arctic rages for eight months of the year. The cold covers the rivers, lakes and seas with ice and the violent winds, snowstorms, and severe frosts of —20-40 and even —50 °C are not a joke. Until recently scientists believed that the Arctic Ocean froze all the way from the Eurasian continent via the pole and to the American continent. Actually, unfrozen polynyas can always be found in the very heart of the Arctic even during the most severe winter. They are found in the same places every year and some of them have been given names. In 1909 the Greenland polynyas almost forced Robert Edwin Peary to give up his hope of reaching the North Pole. Every subsequent expedition has always found a polynya in the same area.

One of the largest is the Great Siberian Polynya. It was this one that put an end to the attempts of some expeditions to reach the heart of the Arctic, and for a long time the legendary Sannikov Island held the imagination of polar explorers.

The chain of unfrozen open water patches uniting the permanent polynyas is called the Arctic life ring. It is this area, and not the tropics, that attracts the guillemots, certain species of gulls, and other Arctic birds during the winter season. Seals, polar bears and Arctic foxes spend the whole winter here. These polynyas are the estates of the amazing northern whale, i.e. the narwhal.

The narwhal is a small animal. Large males never exceed 6 m in length and weigh up to 1 ton; the females being smaller. Its head with a big forehead and small eyes is quite unlike the heads of other dolphins. It does not have the common dolphin's beak. The lower part of the body is light in colour, while the upper part, and especially the head, is much darker. Large grey-brown spots randomly cover the back and the sides,

The narwhal belongs to the suborder of toothed whales although it has no teeth. Its bottom jaw has not even a hint of teeth although the upper jaw has two rudimentary teeth. These never grow in a female if her hormonal condition is normal. In normally developed males the left-hand tooth alone cuts out. It pierces the lip and grows straight forward, reaching 2-3 m in length and twisting counterclockwise into a tight coil. The reason why only one, left-hand tusk grows with a left-hand thread is one of the mysteries concerning the numerous asymmetries of dolphins.

The tusks make narwhals extremely distinctive and swimming herd looks quite impressive. The animals keep close together and dive and surface in harmony, proudly waving their weapons above their heads. The herd resembles a cavalry detachment attacking an enemy with lances.

Nobody knows why the males need the tusks. It is assumed that the tusk is a mark for the animals to distinguish the sex of other animals during the mating season, or may be it is a weapon for "tournaments". While observing the behaviour of narwhals in the open water in the ice fields, researchers have noticed many times that the animals frequently crossed their "lances" as if they were fencing. Nevertheless, angry fights have never been observed.

The prevailing opinion is that the tusks assist the narwhals while hunting. A herd of males surround a school of cod or haddock forming a long arc, but the "lances" are never used at the culminating moment. It is possible to observe in the clear shallow water that narwhals scare off bottom fish, for example, plaice, using their tusks and then catch them. However, it is difficult for them to find and catch fish on the sea bottom. Nevertheless, the tusks cannot be of major significance otherwise the females, who need an abundance of food, would not have been deprived of them by nature.

Narwhals are typical inhabitants of the Arctic. When the ice melts in spring, they go North, reaching in latitudes of

80-85°. Polar explorers on floating research stations meet them quite frequently. The animals go South at the beginning of the winter appearing in the coastal waters of Norway, England, and Holland, and swimming into the Pacific Ocean. Sometimes they enter the White Sea, though their favourite areas are the Canadian Arctic archipelago, the coastal waters of Greenland, and the area near Novaya Zemlya and Franz Josef Land.

The narwhals gather in small groups, but sometimes tremendous herds numbering several hundred or even thousands of animals are observed. They feed on cephalopods but also eat fish, catching mainly slow bottom species. Clearly, it is easier for narwhals to catch these fish with their toothless mouths. In search of food, the animals dive almost 500 m deep and remain there for long periods of time without surfacing.

The cold does not scare narwhals. If the sea is covered with fresh ice, a male will break a hole in the ice with its tusk and a small herd will breathe through it in turn. The narwhals use many holes or prevent some polynyas from icing when the frost is not too strong. When cold is severe, the whole herd may concentrate near one small hole where two seals would not be able to breathe simultaneously. Narwhals can spend several months near these air-holes. This is not emergency for them but their way of life in their winter quarters. Having the capacity to stay underwater for a long time and swim several kilometres without surfacing, narwhals feed well and have a vast hunting area. They wait calmly till the ice begins to move and as the numerous cracks form they can change their hunting grounds.

Wintering in the Arctic is not always without danger. If ice fields move considerably, the open water areas may close up and large herds of narwhals may have to concentrate near tiny air-holes. The water boils in these holes as the animals try to surface in order to breathe fresh air. If the outside temperature is very low, the water splashed by

the panic-striken animals freezes on the walls of the hole, making it still smaller and aggravating the conditions for the animals. Greenland Eskimos sometimes have caught 100-200 narwhals at a single air-hole. But no matter how desperate the herd's conditions, and however narrow the air-hole may be, the narwhals are quite correct in their attitude toward each other in their struggle for access to the fresh air. It is simply amazing how large males, who seemingly mad for air manage to reach the surface through the heap of bodies without hurting anyone with their lethal tusk. At a polynya with thick ice (sometimes more than 10 m) a polar bear will jump without hesitation onto the back of a narwhal, kill and drag it out on the ice. By taking advantage of a situation that is bad for the narwhals, a polar bear occasionally makes huge stores. The predator lies near the hole and throws out onto the ice one animal after another, who became weak due to their lack of air. He can thus provide himself, and eternally hungry suite of Arctic foxes and sea gulls, with food until the spring. A bear was found once in the ice with the bodies of 21 narwhals neatly laid out around him.

If the polar bear is not very hungry, it will devour only the fat and intestines of the narwhal, leaving the meat almost intact. Only a she-bear and her cubs just out from their lair seem to like the meat.

Life at "winter quarters" is quiet and safe until the master of the Arctic—a polar bear—comes across the air-hole. Its visit is not always a tragedy for the narwhals. If pack-ice confines several groups of unicorns to one area, they maintain acoustic communication with each other, apparently visit one another, and in emergencies shelter with their neighbours and never return. Greenland eskimos, who hunt seals, narwhals and white whales in the ice, the latter frequently spending the winter under the ice fields, say that it is easier to catch several white whales from a single air-hole than to catch two unicorns.

Narwhals have adapted well to living under the ice. A large male can easily crush 5 cm thick ice, and if its tusk breaks the animal will not have caries. The bone tissue regenerates along the edges of the broken tusk and the damaged spot is closed with a bone filling. Narwhal vision is also well suited to Arctic conditions. Their eyes are nearly completely covered with skin that protects them against overchilling. Only the pupil and part of the iris, which is rich in blood vessels carrying warmth, can be seen through the slit between the eyelids. In addition their intraocular fluid circulates quite rapidly thereby protecting the eyes and the light sensitive receptors of the fundus of the eye against chilling. A certain optimum temperature is required for the normal operation of the eye's receptors and for transmitting stimulation along the nerve fibres. Undoubtedly, everyone has experienced a loss of feeling in the skin on the hands when working in very cold water. A bad wound can occur in these conditions and the wounded person would feel no pain. Such an organization of the eye, protecting it against chilling, indicates indirectly that narwhals need their vision.

Beside human beings and polar bears, narwhals have one more enemy, namely, killer whales. Eskimos maintain that narwhals live among drifting ice fields and enter fjords that are not visited by the killer whales. When the killer whales attack, they try to kill their prey as quickly as possible so that the wounded animal does not disappear under the ice. Having detected a herd of narwhals, the predators dive down deep, sneak up and, surfacing swiftly, kill a surprised narwhal by a blow in the belly. If the killer whale misses, it attempts to break the narwhal's back by hitting it with its tail. When the school of killer whales hunts, two of the larger animals attack a narwhal from both sides and squeeze it between their bodies until the prey has been choked or its ribs are broken. Once the narwhal is dead, the whole

school rushes at the corpse and it disappears in a few seconds.

Very little is known about the family life of the narwhals. Charming blue-grey animals with black heads can be born at any time of the year and the young are 1.4-1.7 m long. The "boys" are not born with their tusk; it is the "wisdom tooth" of the narwhal and cuts out later.

Scientists assume that the narwhals have a good sonar. It is pitch dark beneath the ice fields during the Arctic night. The animals would not survive without a reliable sonar as they would be unable to find food, polynyas, and even their own herd.

The narwhal is the closest relative to the noisiest dolphin—the white whale—and the sounds they emit can be picked up by the human ear. Narwhals generate thunderlike peals, groans, heavy breathing, gurgling and sharp whistles that end with sudden explosions. These sounds can be heard from under the water, through the ice, the bottom of a boat, or the hull of a ship.

Several years ago American scientists decided to examine the sounds emitted by narwhals. They had had some experience of keeping unicorns in captivity. The animals lived at "Niagara-Fox" in the USA and in the Vancouver seaquarium in Canada, where visitors could see a whole school of polar whales. However, narwhals have become very rare during the last decades, and it is very expensive to hold them captive. The researchers had therefore to go and search for the animals themselves. The expedition found two schools in the waters of Iceland. The first school numbered only 10-12 whales, though the second school comprised about 50 animals. They managed to approach it very closely. The school circled around a few metres away from the hydrophone, but the sounds emitted by individual animals were absorbed in the total chorus. It has been exceptionally difficult to differentiate and analyse them. And still the scientists determined that the sonic clicks were generated in the 1.4-24

kHz range at a rate of 300 clicks per second, and the brief squeals lasted up to 0.1 s. Unlike bottle-nosed dolphins, they do not increase the frequency of location pulses when they approach an obstacle. Nothing else is known today about the echolocation faculty of narwhals.

ARCTIC CANARIES

All whales can utter sounds. However, the white whales are the noisiest ones. Their repertoire is quite extensive. The animals emit squeaks, screams, gritting sounds, apparently, for the purpose of location. Besides that, they utter sounds that resemble loud knocks, toneless groans, squeals, whistling, twittering and warbling, reminding those of birds. It is not without reason that the Norwegians have nicknamed the white whale canary. The white whales can howl and scream piercingly. It is males that howl during the mating season. When a whole school howls, the noise is terrifying.

The sounds emitted by a white whale are within the 0.5-25 kHz range. The clicks are characterized by the high frequency, and the animals generate them in short series of 15-210 clicks per second. A white whale's sonar is similar to that of a narwhal by its physical parameters.

A white whale is a large dolphin. The males can grow to 6 m in length and weigh up to 2 tonnes. The largest animal known was caught in 1929 in the Ungava Bay and was more than 8.5 m long. The females are smaller than the males while the young are rather small—only 1.5 m in length—but they grow rapidly feeding on mother's milk, which contains 27-33 % of fat.

The white whale has no beak. The round head with a large forehead is separated from its body by something resembling a neck. The front flippers are wide. Their fingers have 8 phalanges, which is considerably more than in other

mammals. Sometimes the fourth or the fifth finger splits into two, and then the animals have six digits.

The white or slightly yellowish colour of their bodies explains their name. A school of these large white animals, which can be clearly seen in the greenish waters of the Arctic ocean, creates an unforgettable impression. The white colour makes it possible for the animals to hide amidst ice and to escape their major enemies—the killer whales—who cannot notice the motionless hiding white whales. However, the moment a dolphin loses its self-control and takes off, its fate is decided. It is assumed that the white colour, which helps them to lose less heat, may be a special heat-insulating device. Most probably this assumption has no grounds because the young which ought to suffer more from cold are more coloured. The infants are light blue-grey in colour and darken gradually turning dark blue by the age of 3-4 years, and only then do they begin to acquire a light colour.

The white whales are widespread throughout the Arctic Ocean, the Bering Sea and the Sea of Okhotsk. They visit the North Atlantic and range into deep fjords. They inhabit the Ob inlet and the White Sea almost permanently. Several years ago a large school entered the Teribersk inlet in the Barents Sea. White whales appear frequently in the Baltic, ranging up the Gulfs of Bothnia and Finland. They enter big rivers, swimming hundreds of kilometres upstream. These animals have been observed 1,500 km upstream from the mouth of the Yukon. They have reached Quebec and even Templen on the Saint Lawrence River. They have swum 900 km upstream the Pechora and reached the Polar Urals. Schools of white whales have been 1,500 km upstream of the Ob beyond Khanty-Mansiisk, and entered the Irtish. In the Yenisei River they go 800 km upstream and reach Podkamennaya Tunguska. When the Amur River was calmer, they reached Khabarovsk and even the mouth of Arguni, which is 2,000 km away from the sea.

White whales live in families or small groups of two to four animals, i.e. a mother and one to three young. The family, which is headed by a female, is the basic structural unit of the dolphin community. When the animals join into tremendous schools, they still keep in their family groups. The males swim in independent schools from the late autumn until the spring. They join the females when it becomes warm. The school is then headed by the males while the females follow with the young.

The animals sometimes gather into huge communities. A school over 20 km long was once detected in the Sea of Okhotsk in 1930. Family groups of white whales were found all around Academy Bay in the Sea of Okhotsk in October 1943. They covered an area of 1,200 sq. km. In both cases there were at least 10,000 animals in school.

White whales may remain submerged up to 15 minutes and will not dive very deep. Evidently, they are unable to dive deeper than 40 m. If the school is moving quickly (20 km/h), the animals remain submerged for 20-40 s, and are very rarely submerged as longer as 1-1.5 min. In spite of this they swim under the ice without hesitation, using echolocation to probe for the cracks and polynyas where they can ventilate their lungs. This operation is performed very quickly and requires only 0.7-1.2 s.

The animals are very well adapted to living in ice-covered seas. Like narwhals, they do not have a dorsal fin as it would be impossible to protect it against injuries. The lack of the fin is such a characteristic feature that the white whale species is called *Delphinapterus*—finless dolphins. The animals can break easily new ice up to 15 cm thick by knocking it with the backs of their heads; they break thin ice by pushing their backs against it. When a sheet of ice is being pushed up by a school of white whales, it begins to rise and break into pieces. Bruises and scratches are not hazardous for the animals. A thick and rough hide covers

an animal like armour, protecting the blowhole area, the forehead and the end of the bottom jaw.

The white whale feeds on fish like herring, capelin, saury, navaga, haddock, cod, and smaltings. They also like crustaceans. In the Sea of Okhotsk they feed on salmon, humpback, and gobies. Young that are weaning feed on shripms and small fish like capelin.

The animals will not touch big fish because their teeth are not adapted to chew food. The biggest fish ever found in the stomach of a white whale weighed about 5 kg and was 55 cm long.

Very little is known of the family life of the white whales. A single young is born by a female, but whether this occurs annually or not is not known. It is assumed that there is a two-year interval every 3-4 years between each new gestation period. A delivery is completed in several minutes and the mother feeds her suckling for about two or three, or possibly six months. The sucklings are still feeding on their mother's milk when the mating season begin. Three or four males select a lady-love. They are very active during this period and sometimes there are fights. They woo so insistently that a female is driven sometimes to complete exhaustion or even death.

The white whale has very few enemies, which are killer whales, polar bears, possibly walruses and Greenland sharks. Beside that, helminths. If the animal is lucky enough to escape all the hazards and diseases, it may live up to 25 years. However, such old-timers are very rare. The maximum life-span of a female is 32 years, while with a male it is 40 years. White whales are less encountered in captivity than other dolphins. A small female was demonstrated for the first time in the Boston seaquarium where it lived for two years. The animal was completely tamed in that time. It permitted to be caressed, and to be harnessed in a light carriage, in which it carried passengers around the basin.

White whales have also been kept in the New York and some other seaquaria. Nevertheless, they are the one of the least studied dolphins.

NOT ONLY AUKS

The gray whale is not the biggest animal in the world but it is certainly not a little one. It is usually 15 metres of blubber, meat and bone, and weighs 20-35 tonnes. It inhabits the Northern hemisphere and once numerous gray whales used to inhabit the Atlantic Ocean. They often visited the Baltic Sea and ranged into the Finland Bay almost up to Kronstadt. Today they have been preserved only in the Pacific Ocean. Years ago there were two independent groupings there. One of these, called the Okhotsk-Korean one, was exterminated almost completely by Japanese whalers, that was greatly accelerated by human activities in the areas they used for reproducing. The other grouping, the Chukotsk-Californian, has been preserved better. In 1947, when the herd numbered only 250 animals, it was banned to fish the gray whale and today the herd numbers more than 8,000.

The whales spend the summer in the Sea of Okhotsk, the Bering and the Chukotsk Seas, the waters of which are abundant in food. The animals swallow a tremendous amount of microcrustaceans, polychaete worms and even algae. They accumulate so much blubber that in winter they hardly feed at all. At the beginning of the cold season they migrate South, where they mate and give birth in the lagoons of California and Mexico. To do this they cover distances of 6,000-9,000 km, racing sometimes at speeds of up to 18 km/h. The young ones are quite big, being 3.5-5.5 m long. They feed on their mother's milk for about 6 months.

The habits of the gray whale differ from those of their relatives. They are not fond of the oceanic spaciousness and keep close to the shore, practically never leaving a five-kilo-

metre coastal zone. In winter it goes to the warm shallow waters in bays that are not visited by killer whales, who are the worst enemies of these fat giants and their young. The gray whales of the Californian herd are lucky in that their winter quarters are located along a 600 kilometre uninhabited sun-scorched sandy beach. The female finds a secluded place and delivers her offspring in any tiny lagoon, behind any shoal that separates the beach from the ocean. The largest maternity home is in the Scammon lagoon, which is separated from the ocean by a barrier of sandy dunes. About 1,000 whales shelter here during winter in the crystal clear water among the low flat islands, reefs and shoals. The mating games also occur here. Extending their heads above the water surface, the males look for their brides and, seeing a lonely female, rush to propose to her. When the whales leave the hospitable shelter two to three months later, the lagoon is a dirty pool with muddy water that is left by the giants.

The whales feel quite free at the American coast. Thousands of people watch for their well-being vigilantly. Very popular tourist paths lead in their direction. Tour companies charter ships, launches, aeroplanes and dirigible airships. Special observation towers with powerful spyglasses have been built on the shore. Thus, the whales are reliably protected against poachers and while it is good for the whales, the profits are good too and no less than from whaling.

Gray whales feed in quite an unusual manner. They are the only whales that go down to dig in the bottom sediments. Taking in a full mouth of bottom mud, the whale filters it through a special apparatus, consisting of 130-180 platelike structures of baleen. They swallow the remaining worms, crustaceans and other bottom organisms. It is not surprising that the muzzles of old whales are covered with numerous scars and their stomachs always have a store of stones. The whales also cut plankton. Using their tail like people use a spoon in a cup of tea, they stir up the water into a tur-

bulent whirl, in which the plankton concentrates due to centrifugal force, and then the animals swallow this live gruel.

The gray whales always migrate along the same routes, which is the reason why they easily infect one another with their various parasites. Herds of whale lice, which are small cyamids, crawl on the hairy muzzle of the whale. They cling to the leathery skin using their hind feet, especially on the lips and the genital opening, and gnaw their hosts without any scruples, leaving deep ulcers in the skin.

Neither the cyamids nor their larvae can swim. If a wave were to wash the parasites off the deck of their host, they would drown, a pitiful circumstance for a purely marine creature. It would seem that the whale lice are doomed to extinction, but they flourish. The parasites cling to the skin of their host so tightly that no wave is strong enough to wash them away. The whales infect each other when they are in close contact as they mate or deliver or feed their young.

The acorn barnacles, which build up shells and lead an immobile life, are even more disgusting. They dig deep into the whale's skin with the sharp edges of their shells. Goose barnacles, their closest relatives, immediately settle nearby. The latter do not attach themselves to the soft skin of the animal. However, this does not save the whale for this crustacean uses the shells of the acorn barnacles as the foundation of its home. A big crustacean, *Penella balaenoptera*, is up to 32 cm long and resembles a worm, and gnaws 5-7 cm deep into the skin. The number of parasites is so great that if it were not a whale but a smaller animal, it would be devoured alive. Some of the parasites are quite big. Disgusting 40 m long helminths are found in the stomachs of gray whales.

Incidentally, the gray whales were so called because of these unbidden tenants. In fact, the animal's skin is dark, but over the years it becomes stained with numerous light

marks, which are the traces of its unscrupulous drones. The whales swim into shallow freshwater lagoons and river mouths in order to get rid of their skin parasites. These parasites cannot live in fresh water and perish. The whales frequently approach pebble beaches and rocking on incoming waves, rub against the stony bottom to remove these sticking crustaceans.

The gray whales reproduce only in shallow waters. An infant can neither swim nor dive. Its mother and "aunts" carefully watch that the baby does not drown. The specific weight of the infants is much higher than that of the water and if the young is left alone, it would drown no matter how desperately it beats with its tail. The mother "carries" her baby for several months in her "arms", pushing it onto her back and supporting it with her fins. Most often she holds the baby on her pectoral fins at the breast or the head, pushing it forward with much effort so that the restless naughty child can swim on its belly with its head above the water.

A female feeds her child on her side, supporting it with her caudal fin. They cannot be distracted during feeding because the child might choke. The young can only be delivered and nursed well in small lagoons that are protected from violent storms and heavy ocean waves. These "maternity homes" and their "postnatal departments" must be preserved for the well-being of these gray giants.

Their love for shallow water is fraught with danger. If the whale gapes or forgets about an ebbing tide, it might run aground. Gray whales do not panic in this case; they lie still in the shallow water, preserving their strength and hoping that the next full tide will free them. Mothers will not leave their young that have gone aground. They return with the tide to take their little ones away.

This attachment to coastal waters means that the gray whale is continuously within our eyesight and consequently it has been studied better than any of its relatives.

Scientists were nevertheless not unanimous about whether gray whales are able to utter any sounds. A special research was carried out by the scientists of the US Navy's Center of Underwater Marine Research in San Diego. Their research vessel the USS Saluda followed these giants for more than three and a half months in the open sea. They heard 280 whales and made 230 records of the sounds they emitted. The analysis of these records indicated that gray whales emitted a variety of sounds such as sighs, gurgling, knocks, and most frequently groans, which constitute 87 % of all their sounds. The animals groaned day and night, swimming alone or in schools. But not all the whales groaned: some two thirds of the whales being silent, but the noisy ones could groan 50 times an hour.

The groans are sounds of great intensity (up to 160 db) with a duration of about 2 s, being from 20 to 200 Hz in frequency. The purpose of the sounds is still unclear but they could be intended for echolocation. If so, then it is a mystery why not all the animals generate location pulses even during the night. Possibly, they are communication sounds, or the groans may be responses to external noises, i.e. the noise of the nearby waves washing ashore, or distant storms. It is known that sea gulls and loons also moan before a storm. And finally, the groans may only be an expression of love. The winter is the time for love, the time for finding a loved one, and taking her heart. Who would not groan at this time?!

BLUE MIRACLE

The southern hemisphere is more severe than the northern one. The skies at latitude 40° South are always covered with dark clouds, and steel-gray waves rock the ocean. If a sun beam breaks through such a gloomy day and ocean turns turquoise bright, it means that the feeding grounds of the blue whales are somewhere nearby,

The Antarctic waters are the last domain of the giants of the sea. The blue whales are the largest animals that have ever inhabited our planet. A newborn can be 7.5 m long and seven months later the 16 m creature is still suckling its mother's milk. An adult male in the prime of his life might be 30 m long and weigh 150 tonnes. Every other species of whales seem to be starved when compared to these colossi.

Whale milk is highly nutritious and the young one feeding on this high-caloric food grows with really astronomic speed, gaining on the average 75 g/min or 100 kg/day. The female's nipples are usually hidden in special pockets and are not visible from the outside. The female lets them out when the suckling tells her that it is hungry. The pockets for the nipples are very convenient when the young one is 7 months old and it must be weaned. The hungry child has no other choice but to follow the example of its parents, open its mouth and try to fill its stomach with small fry.

An adult blue whale is extremely handsome. Its back is light-blue in colour, and the folds on the belly are decorated with an ochre-yellow film of diatoms. The small dark-brown eyes seem kind and their bluish tint adds an intelligent expression to the animal. Once the ocean was adorned with chains of the turquoise backs of the giants, who surfaced to ventilate their lungs.

The life of the blue whales is full of secrets. It is assumed that they create families for the whole life. The couples are very friendly and continuously exchange various signals and always act in agreement.

When a young is born to a family, the whales carefully nurse their only offspring until it is old enough to start wandering the world alone or together with one or two others of the same age, growing and fattening.

Blue whales feed at the very surface. By opening their jaws wide, they comb schools of small crustaceans. By keeping their mouths open for half a minute, the whale contracts

the muscles of its cheeks and then by pressing its three-tonne tongue to its palate, it compresses the catch. The sea water filters easily through the dense grid of 300 plate-like baleen structures suspended from the upper jaw, and the food is swallowed. The giant must have two tonnes of plankton in its stomach to be satisfied.

If the catch at the surface is small, the whales dive 30-40 m deep in search of dense clusters of small animals. Surfacing after being submerged for a long time, the whales let out their famous fountain, which is a jet of compressed air saturated with steam. Emerging from two closely arranged blowholes, the narrow jet forms a plume 15 m high (the height of a five-storey building). Hanging in mid air with drops of condensing moisture, these high fountains betray the whales, informing whalers of their whereabouts.

The blue whale has few enemies. Killer whales are dangerous mainly for the young ones. However, they have numerous parasites. Different helminths are found in their intestines, lungs, and gall bladders. Whale lice feed on the skin of some whales, especially those in the antarctic region.

The whales are helped somewhat by flying medical orderlies. When the blue whales reach the polar islands or the uninhabited coasts of South America, these flying orderlies—the phalarope birds—land on their backs between two dives and peck off the crustaceans if the time permits. While the whale dives in search of food the birds soar in the air, looking down into the clear water for the animal, and settle on its back the moment it surfaces.

The blue whales utter different sounds, including high-frequency ones in the 21-31 kHz range. These were recorded by the Norwegian whale-boat "North Star". Investigations of the vocal abilities of the cetaceans started only recently, when very few of the blue giants were still alive. Long cruises are required today to find a blue whale in the ocean.

Their huge dimensions have turned out to be a real misfortune for the blue whale. The 50-150 tonnes of excellent

raw material they yield, a quarter of which is blubber, is a fortune. The blubber is used to produce soap and margarine while glue, gelatin, and bone meal are produced from the bones. Their enormous livers are a tremendous store of vitamin A. The endocrine glands are used to produce some valuable hormonal medical preparations. The blood and internal organs are perfect raw materials for the production of fertilizers. The meat of the blue whales is quite tasty and it is popular in Japan and Norway.

The obvious merits of the blue whale sealed its fate. When summer came to the southern hemisphere, the blue whales rushed to fatten in the polar areas, while their northern relatives went for the summer to the coast of Chukotsk, the northern part of the Atlantic Ocean and the Arctic Ocean. The whalers overtook them there, concerned only with filling up their holds as fast as possible. Blue whales made up 75% of the catch 40 years ago. The catch of blue whales has dropped sharply to 1% during the recent years.

Whaling was barbaric, without any rules, limits or norms. The situation was aggravated because the habitat of the blue whales is far away from the coast in international waters. No one owned the blue whales, and so no one cared for them. The owner of the whale was the one who harpooned it, and whalers made every effort to do so.

Whaling was regulated only in 1946, but it couldn't change anything and the number of whales has continued to drop at a terrifying speed. Strict limitations were endorsed in 1964, and then the catching of blue whales was banned totally. It is a pity, but it was too late. According to the calculations of some scientists, the world oceans are only inhabited today by about 300 blue whales. Such a drastic reduction in population leads to the loss of many species' ability to reproduce their number and they might disappear entirely from the globe.

Thus, the prognosis is unfavourable for the blue whale. Today, the animals wander the ocean in singles or small

groups. The chances are very poor of finding a spouse during the winter mating season because it is quite easy for them to miss one another in the thousands of square kilometres of the Pacific and Indian Oceans. No assurance exists that this encounter will occur in the remote future. It might happen that the natural death rate of the whales will exceed the birth rate, and then they will be doomed. Mankind is helpless for it is impossible to arrange for their artificial reproduction.

Blue whales reproduce very slowly. It takes five years for them to become adults. Their gestation period is about a year and a female will feed her young for another 2-3 years, nursing only one offspring. As a result, the female delivers only two young ones by the age of ten. In total, the female will deliver a maximum of 10 young during her life-span of 20-30 years.

If normal reproduction of the whales is possible, and the ban on whaling is strictly observed by all the countries, their number will increase. Nevertheless, this will be so slowly that the whaling of 4,000 specimens, which was the number planned for 1964. will be possible not earlier than in 70-75 years. It is quite enough time to consider the problem of setting up whale farms.

Scientists do not consider today that such projects would be science fiction. It is unnecessary to arrange closed areas in the ocean. The animals ought to be kept under semifree conditions. It would be possible to form herds during the polar summer in areas rich in krill—tiny shrimplike creatures, the basic food of the blue whale. To this end it would be necessary to understand the sound signalling system of the whales and to study their habits. Older animals who have gained their maximum weight by the autumn might be slaughtered, the rest of the whales would be freed into the warm equatorial waters for reproduction.

It would be extremely tempting to set up whale dairy farms. A young one sucks 600 litres of yellowish milk from

its mother every day; milk contains 53% of fat with a pungent creamy flavour. The same amount of fat, that is melted from the body of an adult whale could be obtained by milking a female for 80 days!

It would not be impossible to milk the females in the future. Even predatory whales, i.e. cachelots, are not aggressive toward humans unless they are attacked. The milking process should not be labour-consuming. Unlike the offspring of most mammals, young whales do not have to suck. This would be rather difficult to do underwater. The females contract certain muscles and inject some "cream" right into the mouth of their baby. Thus, it is only necessary to learn how to stimulate spontaneous milking and design an appropriate milking device to obtain the whale milk.

The possibility of setting up whale farms seems to be a fairy-tale today, but a flight to the moon seemed to be shear fantasy only 20 years ago. Biology is currently advancing in gigantic steps. All-round mastering of the world oceans is on the agenda. It is quite possible that these farms would be highly profitable and would permit mankind to employ the full value of the antarctic oceanic pastures, which are today practically wasted.

Fifty years ago herds of blue whales consumed about a million tons of krill and abundantly fertilized the ocean with their faeces, creating conditions for the rapid growth of plankton. Today the huge mass of krill is untouched. The biologists have not evaluated yet the effect of this factor. Swarms of crustaceans exterminate an enormous amount of plankton, including fish roe and larvae. The fish fry, that have not been eaten, obviously stay hungry.

Will not the extermination of the whales lead to the impoverishment of the fish stock? This is another reason why scientists should seek for methods of increasing the blue whale population. The creation of whale farms to utilize these valuable animals on a planned basis is another stage in mastering the resources of our planet.

MAXI, MIDI, MINI

Leonid Isaakovich Mandelstam who was to become an academician was once expelled in 1899 from the Novorossiisk University, which was the name of the University in Odessa. His participation in student demonstrations had not been forgiven. Deprived of the possibility to complete his education at home, Mandelstam went to Strasbourg, where he was admitted to the University. Later he started research at their famous Institute of Physics, which maintained its traditions as one of the best experimental schools in the world. Being a student he was fascinated by the vibration theory and he remained devoted to it all his life.

Mandelstam is one of the great personalities of physics. He always had broad deep opinions, as well as being clear, laconic and complete in thought. Dealing all his life with vibration, he never risked defining it. Apparently, it was difficult for him to do so.

We have to start indirectly to explain the nature of acoustic vibration and its behaviour. The best thing is to observe a wave on the surface of a liquid. When you throw a stone into a pond or a pool, concentric waves propagate across the surface, gradually loosing their height until they are entirely attenuated.

When looking at a stormy sea, there is the involuntary impression that the huge waves rise up due to the thrust of wind and take off for a stroll across the ocean. This is an illusion. Look carefully at objects dancing in the chaos of the foam. They fly up to the wave crest, run along it a little, and then slide down the rear gentle slope to the same spot where their run began. The rolling waves pick them up again, but going up to the wave crest, they return each time to the same spot, cycling around a closed path. This means that the water too must stay in the same spot. It

simply swells up into a wave above the surface and drops down again to form deep pits.

Water helped Galileo to understand that an object, generating a sound, vibrates creating waves around it. The experimental device he used was a crystal glass, lowered almost to the edge into a vessel containing water. Galileo tapped the glass to make it produce sounds and then he saw tiny radial waves running away from the glass.

The advance of acoustics was very slow. It was only clarified finally in the 17th century how our ears perceived the vibrations of a bell as sound. It appeared that some medium was required that could transmit the vibrations of the sound-making object to our ear. The German scientist Otto von Gericke discovered the medium was air. As the air in a glass chamber surrounding a bell was pumped out, the bell sounded weaker and weaker.

Waves at the boundary of two media are only a particular case of vibration processes. Spherical waves will propagate outwards in all directions if you strike a bell. True we can only see them if a sun beam lights up numerous specks of dust in the air. Immobile before the knock, they start to move around closed orbits when the bell rings, eventually returning to the initial spot. Gas molecules perform the same motion. If it were possible to observe them, we would discover that at certain moments they collect together, while at others they disperse. Consequently, acoustic waves are a rhythmic change of pressure.

Waves propagate in any medium, be they liquids or solids, in a similar manner. Gericke learned this in his experiments. He used his bell as the sound source and fish as the sensing instrument. The scientist hit a bell on shore and then put soft bread into the water. In a short time the bell started to collect large assemblies of fish near the shore. Evidently, it would have been simpler to dive into the pond and see if acoustic waves could propagate in water, but for some reason Gericke never thought of it.

A human ear can only sense, i.e. hear as sound, air pressure vibrations at a frequency from 20 to 20,000 cycles per second. The sound is not perceived to be continuous when the pressure alternates less than 16-18 times per second. Such slow pressure vibrations are called infrasounds in acoustics. The human ear cannot sense pressure changes above 20,000 cycles per second. Hence it will not inform the brain about them, which is why there is sometimes an apparently complete silence around us. These vibrations are called ultrasounds.

The word "ultra" means "beyond in space, on the other side". It would be a mistake to think that ultrasonic vibration is physically different from common acoustic waves. Most animals sense perfectly ultrasonic vibrations that are inaudible to humans. Our faithful companion—the dog—senses ultrasounds up to 38,000 Hz. Many circus tricks are based on this phenomenon. A dog is asked: "What is two plus five?" Its trainer hurries to prompt the answer, by sending seven signals to the dog using a special ultrasonic whistle; signals the observers cannot hear. The four-legged actor barks in response to each signal, while the spectators are amazed at the talent of the dog.

The world around us is full of inaudible sounds. However, we should not be distressed. Protracted noise can cause severe diseases of the auditory organs and the central nervous system. Man has created such a noisy world all around him that he would suffer. Most machines generate low-frequency noises as well as ultrasounds. Luckily, these do not disturb us when we sleep. These waves cannot be sensed by a human ear but they may be dangerous at certain frequencies.

The velocity of sound must be known for echolocation to be successful. Gun-fire permitted to observe that sound was rather slow and gave a way of measuring the speed of its propagation accurately. Members of the French Academy of Sciences who carried out this experiment arranged two gun

batteries on hills 30 km away from one another. The guns fired twice an hour, and the observers recorded the time required for the sound to reach them from the moment the guns fired. It turned out that the sound covered the 30 km distance in about two minutes. A sound would need more than a day and a night to travel around the planet.

The speed acoustic waves propagate is not dependent on either the cause that generates the waves or their frequency. It depends on the character and the state of the medium in which the waves propagate. Sound propagates more than four times faster in water than in air and travels above 1.5 km/s. If waves propagate in water with a frequency of 20,000 Hz, then there will be 20,000 waves in 1.5 km (the distance that sound covers in one second). The number of waves would be five times greater if the frequency was 100,000 Hz. Consequently, the wavelength would be five times shorter. Thus, ultrasound vibration generates small waves, while infrasound is conveyed by long waves. Waves that are audible to the human ears are medium in length. Galileo was the first to ascertain that a sound's pitch depends on its wavelength. In the experiments with a glass generating sound in water his attention was drawn to the fact that the ripples were two times smaller if the sound's pitch went up an octave.

The magnitude of an acoustic wavelength is directly proportional to the velocity of sound. The longer the distance the sound travels per unit time, the longer the wave. Hence, an acoustic wave with a particular frequency propagating in air, would be 4.5 times shorter than it would in water. For example, the wavelength of ultrasound with a frequency of 50 kHz (i.e. 50,000 c.p.s.) in air is 6.8 mm, while it is 31 mm in water.

An important characteristic of sound is its intensity. The tympanic membrane in our ear begins to vibrate due to the energy radiated from a source of sound via acoustic waves. The greater the amplitude of the acoustic waves and thus

the greater the propagating energy, the more intense and louder the sound.

It should be remembered that the loudness of a sound, the amount of energy conveyed by the sound waves will not affect their velocity. It is easy to check this. Ripples from a stone thrown into water propagate from the spot the stone hits the water surface and gradually attenuate, but their speed keeps constant. Even Galileo knew this. While attending services at church he was, nevertheless, a physicist. Observing some chandeliers swinging, he found that the vibration period was constant no matter what the amplitude of their motion. The scientist couldn't go and bring the water clock, he usually used, as the church would not have forgiven him. He had to resort to improvised means and used his own heart beat to measure time. Unconvinced that his clock was not perfect, he compensated its accuracy by doing the experiment many times. Galileo had enough patience to record a thousand measurements to be convinced that his conclusions were correct *.

What happens to an acoustic wave when it meets an obstacle? Let's return to the pool, into which we threw a stone. Tiny grass blades growing through the water will not hamper the propagating circular waves. Thick reed stalks do present an obstacle for the waves, and a stone sticking out of the water breaks up the ring. The water does not ripple beyond it. The behaviour of acoustic waves is just the same. If their length is smaller than the obstacle, they reflect from it with a shadow zone "upwind" of the source and no sound propagates into it. An acoustic wave that changes the direction of its motion is an echo. It is necessary to radiate ultrasounds with a very short wavelengths to receive echoes from small objects, especially in water.

The character of an acoustic wave depends on its length.

---

* The period of a pendulum is constant only at small angles from the vertical.

The sizes of the sources of sound audible to a human ear are usually smaller than the radiated acoustic wavelengths. The sound waves then propagate in every direction from the source. The situation is different when generating ultrasounds. The dimensions of the sources may exceed significantly the wavelength of the radiated wave. This source will generate plane waves. They propagate in a direction perpendicular to the plane of the source. A sound beam is generated, which permits to concentrate the entire energy of the sound in the required direction, to send the sound signal further, and to receive a louder echo. The sound intensity increases sharply as the vibration frequency increases. It is simpler to generate high-energy ultrasounds than it is to get audible sounds of the same intensity. Hence, it is better to use ultrasounds for echolocation.

Ultrasound has another aspect, it attenuates very rapidly. The higher the frequency a sound has, the faster it is absorbed. A ten-fold increase in the frequency is accompanied by a 100-fold times faster attenuation and consequently the distance it propagates reduces drastically. Nevertheless, it is more advantageous to employ ultrasound for echolocation than low-frequency sounds, because it is difficult to generate the latter in a narrow beam. Propagating in all directions, the low-frequency sound, which is audible to a human ear, is absorbed by the medium and scattered through a larger volume. As a result, its intensity drops and it is attenuated. Considering that ultrasound is attenuated in water 1,000 times slower than in air, it can be maintained with assurance that aquatic animals use ultrasound for echolocation. However, this sonar can only be used for probing only the nearby space. It cannot be used for remote orientation.

WHENCE?

The acoustic situation on the planet was quite monotonous when life just originated on our planet. Thunder rol-

led sometimes, or the wind whistled. Waterfalls cascaded from rocks, breaking up the silence, or the latter was disturbed by the noise of the sea breaking upon the shore, and by volcanic eruptions. Who could have been interested in these sounds at that time? Sounds of "interest" appeared only when highly developed animals spread and having learned to move actively, wandered across the world devouring one another. These sounds were biological in origin. They were generated by the animals themselves and naturally contained certain information concerning the sources of the sound. It was worth while to get interested in this information.

Interest in sounds of biological origin was the driving force for the ancient ancestors of contemporary animals to develop a sonic analyser. When sound-sensing organs were good enough, the animals could use sounds for mutual exchange of information too. It then become necessary to produce audio signals intentionally.

The basis of any musical instrument is a vibrating element, which generates the sound waves. This can be any elastic body that will vibrate in response to a tap, knock, or to friction. A resonator is used to amplify the sound. Air is usually used to this end. It is elastic; a gas column vibrates through its entire length like a steel spring. It can vibrate at any frequency, but the air vibration attenuates very soon. The walls of a vessel can also resonate.

Some musical instruments are simply vibrating elements, for example, xylophones, cymbals, hand and big bells. An air column resonates in a flute whose walls take no part in amplifying the sound. The air as well as the metal walls vibrate in the brass instruments, e.g. trumpets, French horns. The sound is amplified substantially. The "musical instruments" of animals consist of either a single vibrating element or they have a resonator too. This may be a membrane, an air column, or the walls of a cavity containing gas (which might not be air) under certain pressure.

Nature has supplied living organisms with acoustical sources of most different designs. They are quite primitive in insects. Hymenoptera employ crude bow instruments resembling a double basses. Locusts rub their legs over their rigid wings while grasshoppers generate sounds by rubbing their elytra. Crickets have 150 triangular prisms on the rubbing surface of their wings, and the vibration of four webs amplifiers the sound.

The cicadas of tropical countries have cymbals, which is an amazing musical instrument. The males are the only ones to sing. They have a pair of drumlike membranes on the bottom side of the first segment of their abdomens. These are called the cymbals. Each membrane has a special strong muscles. They pull in the convex part of the membrane and then free it. They continuously pull it in and let it free. The sound is generated in the same way as it is from a metal oiler or a tin can. If you press in the bottom of a can with your finger and then let it pop out again to its initial position it makes a characteristic sound. The chirring of the cicadas is audible any time of the day or night and they are extremely emotional when it falls dark. It is impossible to imagine a night in the south without the incessantly chirring cicadas. Tropical species have very strong voices. Their song resembles the sound of a circular saw or the roaring of a motorcycle, while the pitch is not lower than a locomotive whistle.

Fish also generate most different sounds, although, apparently, they have no special means to do so. Some species produce sounds by rubbing their gills. Carp species generate sounds by gritting their teeth, which are hidden deep in their throats. Many fish use the swimming bladders as resonators. Sound is produced by contracting special membrane muscles causing vibration of its walls.

By means of these simple attributes fish generate sounds that resemble tapping, gritting, whistling, creaking, sobbing, cackling, mewing, or shorting. A yellow mackerel, when it

meets its girl-friend, grunts with pleasure. Anglefish grunts like a sucking pig. At spawning time a round goby creaks, beckoning a female, and begins to croak when he sees her. The Alasca blackfish barks like a dog, while sea dogs prefer to grunt. Gurnards cackle when they send a signal of alarm. A pilot fish produces tapping sounds while swimming so that the pilot shark will not distract its attention. Fish are very noisy when they mate, round gobies chirping and spoonhead sculpin humming. Before fighting the wrasse-ocellatus clatters. The round goby growls like a rusty door hinge. A wrasse (*Crenilabrus griseus*) threatens by drumming, and the Sakhalin sculpin grumbles. A frightened filefish whistles, chirps, and clicks.

Reptiles are the quietest of animals. The sounds, emitted by them, are quite monotonous. Almost all the snakes can hiss threatingly and land tortoises can hiss very loudly. Certain lizards cheep, while skink geckoes rub the scales on their tails and produce strange sounds that remind the rustle of folding parchment paper. The horned adder, the Avicenna adder, and the sand epha have special saw-like scales on their sides. Having coiled up into two half-rings they slide one half-ring over the other, their "musical" scales producing a sound like a hot iron hissing as some one had spat on it.

The rattlesnake uses a rattle, which is made up of six to eight rings of dry skin at the tip of the tail. Coiling up into rings, the snake lifts its tail and, vibrating it rapidly, begins to rattle. The sound of the rattle resembles that of an operating narrow-film camera.

Birds are singers and musicians par excellence. They employ most different musical instruments. The flight of many birds has a characteristic musical accompaniment. It is easy to recognize the species of ducks by the whistling of the wings, and humming-birds by the humming. Evidently, snipes whistle, hum or bleat in the air due to their quill feather. The fourth quill feather in the wing is used musically

by the little bustards. Many birds simply flap their wings; such signals are employed by nightjars, owls, pigeons, and larks. Pigeons and nightjars flap their wings over their backs, while the others do so beneath their bellies. Owls, woodcocks and other birds express their emotions by clicking their beaks. Storks "play" this "instrument" for love serenades.

Some birds have no voice and so have to borrow musical instruments. Tapping beaks on hard soil is a summons for chicks. Titmice and nuthatches use dry bark as a drum, and woodpeckers use dry tree trunks. A roll like that of a drum is their love song and different species of woodpecker drum with different frequencies. Females recognize faultlessly the serenades of their "own" admirers and never respond to the call of a stranger.

Animals use various methods for generating sounds. The main "musical instrument" is the vocal apparatus. This began to develop immediately the ancient vertebrates left the seas. The vocal apparatus existed in amphibians and this was the prototype of the vocal organs in higher vertebrates and human beings. The vocal cords, which are paired folds of mucous membranes that project into the cavity of the larynx, are used as strings. They are tensioned in mammals between the thyroid and arytenoid cartilages in the larynx and form the glottis. When the vocal cords are stretched, the passing air flow vibrates them, thereby generating sound.

It has been determined only recently that dolphins are quite noisy creatures. Beside the clicks they use for location the animals produce a variety of sounds and it would seem that they possess well-developed vocal cords even though for more than 150 years anatomists stated that dolphins had none. Zoologists have managed to detect them recently in bottle-nosed dolphins, disproving the conclusion of the very thorough German researchers of the last century. It turned out that the vocal cords were well developed and it is difficult to understand today why they were missed before.

Researchers in echolocation have long believed that whales generate sound in quite a different way, and the discovery of the zoologists could not shake their views.

The functioning of the vocal apparatus in mammals is closely linked with the respiratory system. But the design of the respiratory tracts of dolphins is quite peculiar and has no analogues in land creatures. Toothed whales do not exercise mouth breathing. The oral cavity and the larynx do not communicate with the lungs. The mouth is used only for consuming food. This novelty is explained quite logically. If the oral cavity were connected with the trachea, dolphins would not be able to open their mouths when submerged. Considering that they lack any other method of capturing prey beside the mouth any other design of the digestive system would be the cause for their starving to death.

Toothed whales are characterized by "nasal" breathing. The word "nasal" is given in inverted commas because their nasal passage opens at the top (in dolphins it is called the rostrum) instead of being at the end of the muzzle, beside which they have only one nostril which is quite big. The respiratory orifice is located at the very top point of the head. Many dolphins only push this point above the water. This type of blowhole makes floating motionless at the wa- surface very convenient, dozing and flapping their flippers slightly so that the vertex would stick out of the water. The blowhole orifice is a powerful crescent-shaped valve, which is a peculiar fleshy plug. It protects the lungs against the inlet of water. The wide nostril reduces the breathing time to the minimum.

The design novelties of the respiratory system are supplemented with three pairs of asymmetric air sacs that communicate with the external nasal passage. These are narrow and arched in the majority of toothed whales. The sacs are arranged in tiers, one above the other. If gypsum is poured into the respiratory system of a dead dolphin to

make a plaster cast, the air sacs would remind mainly three rolls of an incorrect ring shape fixed on the rod of the external nasal passage. The internal plugs are arranged at the orifice of the central pair of sacs. It is possible to assume with good reason that the animals, tensioning the muscles of the sacs, can isolate arbitrarily individual cavities from the rest of the respiratory system, and, developing the required pressure therein and adjusting the size of the communicating orifice, pump the air from one sac to another. It is still unknown what the dolphins need the air sacs for, but the majority of scientists support the idea that they are employed for generating sounds.

The simpliest suggestion is that their sound is generated by air being exhaled through the outer respiratory orifice. If the animals are observed, it can be seen that when they whistle a stream of small bubbles rise to the surface from their respiratory orifices. However, no air emerges when clicks or other sounds are heard.

The vocal cords might be the spot where the sounds are generated, the air blown through them not necessarily being exhaled. It may be drawn into the sacs that could act as resonators. Most researchers long ago decided that echolocation clicks were generated in the external nasal passage when the air is pumped from one sac to another through very narrow orifices. Indeed, weak clicks resembling the location pulses were produced when air under pressure was blown through the nasal passages of dead bottle-nosed and rough-toothed dolphins.

Scientists considered this theory to be very attractive. In fact, the respiratory system of the dolphins has six air sacs and even more narrow passages in the air canals. The musculature of each sac and the internal plugs may function independently. This means that the animals can emit simultaneously several sounds. Observations have confirmed that the bottle-nosed and common dolphins and the pilot whale can emit simultaneously whistles and clicks, whistles

and squeaks, and squeals, barking, and other sounds. It has been assumed that each location click is formed by the summary effect of two (or more) sound sources. If these assumptions are true, many of the riddles concerning the sounds emitted by dolphins will be solved.

The synthesis of several acoustic signals yields quite peculiar sounds. When Johnny Weissmuller was performing Tarzan in the adventure serial, he said that the "Tarzan" scream consisted of voice of the actor, the barking of a dog, the soprano of an opera singer, the sound of a violin string, and the howling of a hyena.

The respiratory system of baleen whales is of simpler design. The esophagus is not separated anatomically from the respiratory tract. The entrance to the trachea is temporarily closed by the epiglottic cartilage only when swallowing food. These whales lack supraskull air sacs, but they do have a larynx air sac. Apparently, sounds are generated in their larynx, and the air sac is a resonator.

A BRIGHT STAR IN THE FOREHEAD

Any animal wishes to see as far as possible and all around so as to miss neither a prey nor danger. Dolphins "illuminate" their way by an acoustic beam. Some very complicated experiments were performed to determine the nature of the beam. The main obstacle in the research was the extreme mobility of the dolphins. The scientists would have liked to keep the animal still in a certain spot in the pond and have it locate an object dropped into the water on command. Arranging hydrophones around the object being located, the researchers would be able to analyse the parameters of the sound in different points of the space, and the problem would be resolved.

But to everyone's despair, nobody could do it this way. It is not so simple to tell a dolphin to stay still in the water and radiate location pulses on command. Beside which,

when research was first started on the echolocation ability of cetaceans, no laboratories had any instruments that could record simultaneously on a single tape sounds picked up by several hydrophones.

American researchers were the first to start investigation of the dolphin's acoustic beam. They had a small shallow round pond, resembling the bowl of a fountain, and one dolphin (*Steno bredanensis*). After long training the animal learned to cross the pond along a diameter, swimming between two tightly stretched cables. Dolphins avoid touching any objects. This, evidently, why the animal was obedient and did not swim beyond the given corridor. The eyes of the dolphin were closed during the experiments with special suction cups, and the animal had no way out but to use its echolocation so as not to run against anything. Beside that, the animal never trusted the researchers completely. It was more prudent to be constantly on the alert.

The research was carried out with meticulous accuracy. The scientists had one hydrophone. They arranged it in a different spot each time round. They had to pick out from the mass of records and compare only those location pulses that were emitted by the animal at the same spot of the pond and when its head was in absolutely the same position. The dolphin had to swim along the same track dozens of times, while the hydrophone was rearranged to a new spot in order to determine the regions in front of the dolphin that were "illuminated" by the acoustic beam, and to see which remained "in the shade". The researchers managed to get over all the difficulties and learned that the higher the frequency of the location pulse, the narrower the beam that radiated it.

The results were not a great surprise to the scientists. It was known earlier that bats also employed a narrow acoustic beam for echolocation. But a new problem spring up, which was to explain how the dolphins could send location pulses in such a narrow beam. The answer to this question could

be received by learning the anatomy of dolphins. The acoustic pulses employed for location must be generated somewhere in the external air passages, and it turns out that the sound is fenced off in the rear by the long bones of the upper jaw and the frontal bones of the skull, which are arranged perpendicular to the jaw bones and which ascend sharply upward and slightly concave inward. In the front the sound is guided by a special formation called a melon, although it is more often known as a fat pad. Plotting these formations in the form of a diagram and indicating where in the drawing the sound is generated and the path of the acoustic beam, we get a drawing of the projector. And indeed, the dolphin's head is a projector, but it projects a sound. The bones of the skull serve as a reflector for the acoustic beam, making it possible to radiate the beam in a certain direction, while the fat pad is the focusing lens to collect a narrow beam.

How the sound projector works is a mystery. Bone is a poor material for reflecting acoustic waves. Ivory, the hardest bone, can only just reflect 35% of the energy of an acoustic wave, while the rest is absorbed by the bones in the skull or transmitted through the bone substance. A comparison of the acoustic properties of the skull bones in different species of cetaceans indicated that the bone reflector in river dolphins, beaked and sperm whales (cachalots) is made of higher grade material than that of their relatives. It is assumed that echolocation is better developed in these animals than in the others. River dolphins inhabit turbid waters or have no vision at all, while beaked and sperm whales dive in search of food to a depth where only complete darkness reigns. Nevertheless, the efficiency of the bone reflector is rather low even in these cetaceans. Why do the dolphins tolerate these considerable losses? Is continuous ultrasound irradiation dangerous for their brain, or not? However, nobody has ever measured the real reflectivity of the live bone of a dolphin. It may well be that it is substantially greater.

It is not unlikely that this is the reason why the acoustic pulses used for location are practically never reflected to propagate backwards.

The melon, or fat pad, is a very good device from the acoustic point of view. It only partially consists of fat. Fat mainly fills the cells in the central part of the pad. There is a certain regularity in the distribution of different kinds of fats and their components, which have different refractivities. The peripheral parts of the pad have more inclusions of nonadipose cells and other tissues, and it is in fact difficult to determine its boundaries. There are neither membranes, nor clear boundaries between the different media, from which acoustic waves could be reflected. They pass through the lens without any loss and are refracted in accordance with the properties of the given section.

The refractive properties of the fat pad are explained by the changes in the speed at which the sound waves propagate through the different adipose substances. Thus the lentil-shaped lens can transform the spherical front of the sound wave into a plane, or even a convex one. As a result, instead of propagating in all directions, the sound is collected into a narrow beam, which is intensified by the focusing. Scientists assume that the dolphins can alter the shape of the lens and focus the acoustic beam, tuning it to the different temperatures, salinities and depths. It is quite possible that the lens may be displaced in space, that would enable the dolphins to change the direction of the acoustic beam.

Indisputable proof on the existence of the sound projector was acquired gradually. Some amazing results were obtained in experiments on a fresh corpse. Obviously a dead body cannot produce any sound itself and so a miniature sound projector was arranged behind the fat pad in order to study the distribution of sounds passing through it. The results of these strange experiments were conflicting. Some researchers determined precise focusing of the sounds, especially

the high-frequency ones, i.e. an acoustic wave with a frequency of 186 kHz propagated in a narrow beam only 17° across. Other researchers could not detect any focusing of an acoustic beam. However, this does not discredit the idea, because all kinds of changes may occur in the fat pad after the animal has died.

The method dolphins use to probe the surrounding space with their acoustic beams was clarified to a certain extent when scientists obtained multitrack tape recorders. It then became possible to record location pulses from two, three or even a dozen points simultaneously, while instantaneous photographing of the animal in two planes by two cameras—one suspended over the pond and the other mounted underwater recorded the location of the dolphin and the direction of the animal's beak to an accuracy of one degree. The shots made by the upper camera showed which hydrophone the dolphin was pointing at while the underwater camera illustrated whether the animal was in a horizontal position, and whether its beak was turned up or down. The numbers of the frames were also stated on the records of the location pulses that helped to determine the position of the head at the moment the dolphin sent a location pulse.

These experiments, carried out in laboratories all over the world, provided sufficient evidence that the dolphin's projector really did transmit forward a narrow and powerful acoustic beam. It "illuminated" the path of the dolphin and enabled it to discern any object from afar. Turbid water was not an obstacle. The acoustic beam assisted it in avoiding danger if a squall blew up suddenly and the sea near the coast became turbid with the bottom silt. The beam aided the dolphin in the pitch darkness of foul weather in autumn. Imagine a large school of dolphins swimming across the night sea and probing it with dozens of projectors. The acoustic beams grow dim or brighten up with new force, rush forward into infinite space, or intersect suddenly on

an object that interested the animals. Enemy planes were once intercepted in the same way by anti-aircraft searchlights.

WHEN YOUR HEAD IS ALL BUMPS

The headlight was an excellent invention. It is used by miners, surgeons, underwater swimmers, i.e. by all whose hands are busy during their work. But it is not useful to probe a wide space by means of a headlight which transmits a narrow light beam. Your neck will get very tired! Then how do the dolphins do it? How do they manage to notice everything in due time with a projector that illuminates only a narrow zone, and how do they do so with a head that hardly moves? It is true that a swimming dolphin continuously turns its head right and left. But does it provide the animal with a wide range of vision? It is unlikely. Scientists gradualy began to suspect that dolphins could transmit an acoustic beam somehow in any direction without turning their heads. This was the conclusion of the scientists, whose experiment was described in the previous chapter. The experiments were carried out with four hydrophones arranged in a line at right angles to the movement of the animals, and two cine cameras.

It was not the aim of the research program to study the directivity of the sound transmission, the scientists only wanted to determine where the dolphin hid the projector of the location pulses. The preconditions for this experiment are quite elementary. If the sound source were a point source (what else could it be?), then, by knowing the time required for the sound to reach any three points in space in the plane of the source, there is no problem determining the point where the sound is generated. It turned out during the experiment, that the location pulses never reached all the hydrophones simultaneously for some reason. All the records showed that the acoustic wave reached first the right-

hand (fourth) hydrophone, then the third, the second, and, finally, the first one.

The relevant calculations were made from a considerable number of recorded observations and the results stunned the scientists. It turned out that the sound source was somewhere beyond the right-hand side of the animal's head. Undoubtedly, the sounds should have appeared in the big forehead of the dolphin, and not from one side of it. It was difficult to explain the discrepancy between the calculated data and the common sense answer. After a thorough analysis of the results the puzzled scientists concluded that the illusion of sound generation somewhere beyond the dolphin's head could only arise if the animals rotated their acoustic beam violently. This would explain why the location pulse to the first hydrophone arrived later than to the fourth one. This lag ought to equal the time required for the beam to turn towards the first hydrophone.

In turn, the sequence in the arrival of the sound pulse to each of the four hydrophones is explained by the fact that the dolphin preferred to rotate its acoustic beam from right to left, i.e. counterclockwise, and the source of sound was in the right-hand side of the head.

Despite the view the scientists had held until only recently that the sound only propagated forwards, the observations showed that the location pulse could turn freely in any direction, and could even be directed almost perpendicular to the body axis of the animal.

Naturally we ask: what is it that rotates in the dolphin's head? It turned out that the acoustic beam did not need a turning mechanism. The summary acoustic beam could be transmitted in any direction if there are several sound sources that can be controlled flexibly, adjusting specially the parameters of the generated pulses first and foremost being the phase of the acoustic wave. Only two sources are needed to do this, but a dolphin can have many more.

It seems that certain observations disprove the proposed hypothesis. Some researchers cut the nerve controlling the region of the air sacs on one side of the dolphin's head. It was assumed that loss of control over half of the muscles would cause complete failure in the operation of the sound projector. However, no essential change in sound transmission was observed. The results of this experiment made the theory about the rotation of the acoustic beam questionable. The advocates of the theory parried the blow by assuming that the air sacs on one side operate constantly when generating location pulses. This type of operation is so simple that it need not fail due to the lack of a nerve. The air sacs on the healthy side continue to adjust the generated vibration and the sound projector operates normally.

Evidently, dolphins can also alter the direction of their acoustic beam using the fat pad. As stated earlier, the "acoustic lens" is surrounded with muscular layers, and consequently it is easy to assume that it can change its configuration, forming a wider acoustic beam or focusing it, or by moving it to the right, left, upward or downward, direct the acoustic waves to the given points in space. No one has yet presented any indisputable evidence that this is the way the sound projector works (though it is quite possible that this is just the way the projector operates). However, the fat pad is a too massive formation to change its position in the head of the animal 1,000 times per second.

The hypothesis that the dolphin can rotate its acoustic beam is attractive also because it explains the origin of many peculiarities of the location pulses. The first one is the rapid growth in the sound intensity. Acousticians say that a location pulse is characterized by a steep front. If the location pulse did rotate moving in space, it could focus on the hydrophone the moment the sound gained full power, thereby creating the illusion of a rapid growth in intensity.

Most researchers who have studied the sounds emitted by dolphins recorded location pulses a certain distance away

from the animal. This method has certain drawback. The sound is altered greatly on its way to the hydrophone from the dolphin. It is absorbed, scattered, and dispersed *, and reaches the hydrophone in this distorted form. It is not unreasonable therefore that researchers had always dreamed of recording the sound the moment it was propagated into the water.

The Americans were the first to attach hydrophones to the head of the dolphin, and transmit the sound signals to the shore using a radio receiver. However, no matter how good and up-to-date radio equipment, it always distorted the transmitted sounds somewhat. The path from the hydrophone on the head of the animal to the tape recorder on the shore was too complicated. They then tried to connect the hydrophone on the head of the dolphin directly with the tape recorder on the shore. One can imagine how much wires restricted the movements of the animal, influenced on its behaviour, and distorted the generated sounds.

The scientists experimented then with another method. They designed a miniature tape recorder that was attached to the back of the dolphin. The tape recorder was operated remotely by radio signals. The device was unusual. The recording was made onto a special wire and not onto a magnetic tape as usual, while the recording mechanism was made of water-resistant materials and therefore needed no casing. In essence, there were three interconnected tape recorders that registered acoustic signals from three hydrophones attached to the animal's skin by means of special suction cups.

The dolphin got accustomed to the tape recorder in a very short time and paid no attention to it. The researchers obtained some very interesting results. The hydrophone on the left-hand side of the blowhole recorded whistling, while

---

* Dispersion is the separation of beams passing through refracting media.

the one arranged symmetrically on the right-hand side did not record any sounds. Hence, the whistling was generated in one half of the air passages and could be transmitted forward by the acoustic lens.

Having analyzed the records of sounds from different parts of the animal's head, the scientists became convinced that the larynx and one pair of sacs did not participate in the generation of sounds. Exactly where they are generated is still a mystery. E. Romanenko, a well-known Soviet bioacoustician, has said that we only know positively that sounds are transmitted from the head of the animal.

SECRET CODE

For a long time the researchers have been interested in determining the nature of the dolphin's location pulses which are produced in long series containing dozens and hundreds of clicks. Are they all standard, or is each pulse individual? Can the animals spontaneously change the acoustic characteristics of their location pulses, or is the generation inaccurately controlled, each pulse being accidental? The question was not related to the ability of altering roughly the parameters of the location pulses. It was observed a long time ago that the first and the last clicks differed essentially from the other clicks in the series. Two series of location pulses, especially those recorded under different conditions, are quite unlike each other. It was quite clear that the dolphins could change them spontaneously to a certain extent.

It may seem strange to the reader that there could be anything vague considering that dozens of kilometers of magnetic tape with recordings of dolphin's location clicks are available. Unfortunately, it is still impossible to create experimental conditions that do not distort the signals produced by the dolphins, nor is there any equipment that can

record the location pulse in its original form without distortion or loss of information.

Let's approach this problem from a purely theoretical point of view. It is widely known that it is impossible to grind two components with absolutely the same dimensions on a lathe. There is no reason to assume that the dolphin's sound generator is any better in this respect than something created by man. Consequently, the location pulses cannot be absolutely the same. But how great is the difference? While it is impossible to give an accurate answer to this question, it is clear that the difference is substantial. Two identical pulses will not appear more often than once every 10^{50} location pulses. Thus a school of echolocating dolphins all probing an object in which they are interested, will never transmit two identical pulses toward it.

Is there any essential significance in the small difference between two successive location pulses, and do the dolphins recognize this difference? Most researchers consider that the animals remember something about the last location pulse until its echo returns in order to be able to determine the difference between it and the probe signal.

The location pulses of the dolphins were recorded mainly when they were searching for objects thrown into a pond, or when they were discriminating the shape, size or material of objects lowered into the water. A thorough analysis of these records has established that the animals changed the characteristics of their location pulses every time the situation changed. This occurred when the dolphin encountered acoustic interference in the water. The operation of the sonar is changed if the animal is proposed an exceptionally difficult problem at the limit of its abilities. It then increases the frequency of the location pulses or changes their characteristics. However, the frequency and number of the location pulses are decreased, and their characteristics changed if the same object is shown to a dolphin in a series of experiments.

Location pulses can be divided into two types. One type of pulses are used for probing the space, these are called orienting pulses. The other sort of pulses are used when the dolphin wishes to study some complex object in detail, and to learn how not to confuse it with others that are alike it. These are called discriminating, or identifying pulses.

There is opinion of another sort. Quite a number of researchers have found that when given a complex object the animal did not use different location pulses. The observations confirmed that the dolphins, solving complex problems, do not use the primary echo, that is the reflection of the location pulse from the object, but analyze the acoustic vibrations that are generated in the located object. If a crystal glass is tapped, it tinkles tunefully. Sounds can be generated in any object in a similar manner, although they will not always be loud or tuneful. And what is used for tapping is not very important. The resonance of an object depends mainly on the object itself. Hence, the location pulses ought to be simple in structure and it is not necessary to change their character.

There are thus two different opinions, but which one is correct? Apparently, they are both correct. Dolphins do indeed employ widely the so-called secondary echo for identification and use quite monotonous location pulses to do so. However, only familiar objects are identified by this method. When the animal comes across something new, it studies the object thoroughly, using a whole store of location pulses.

In one experiment a mackerel, the favourite food of the dolphin, was lowered into the pond on a thread. There was nothing unusual about it but the approaching dolphin studied it thoroughly using a variety of different location pulses. The second and third mackerel did not require such all-round analysis, and when the animal had received the fifth or the sixth fish, it used standard pulses, reducing their number and frequency. It seemed that the dolphin had stopped studying the bait, being sure that it was always a

mackerel that appeared in the water and only checked its location. If a banded sea perch was lowered into the pond the next time, a fish dolphins never feed on, or even a plastic toy skittle, it caught the bait but would immediately spit it out, showing the experimenter its displeasure for such unscrupulous cheating. This means that the animal did not know exactly what bait it approached, trusting human decency and not wasting effort to study the bait.

It is quite characteristic that in case of any difficulty the dolphins increase the frequency of their location pulses. It is quite possible that the echo of one location pulse is not enough to examine the situation and the animals accumulate the successively incoming echo-signals. There is certain sense in increasing the generation rate of the location pulses for rapid acquisition of information under complicated conditions. And it really occurs so but the increase in the rate is never very great. Before sending the next location pulse, the dolphin must wait until the echo of the previous one has been attenuated. Evidently, it is beneficial for the animals to receive information using dozens or even hundreds of similar location pulses to discriminate what depends in the echo on the specifics of the object that reflected the sound and what depends on the interference. If the probing pulses cannot be used to locate an object, the pulses must be altered in the hope that the new pulses will be more adequate for identifying the object that the animal is interested in.

Some scientists believe that dolphins can tune the parameters of their location pulses to those of the object being studied. Certain pulses are used for balls, others for cylinders, and still different ones are generated for cones. But today it is only an assumption. It is only known for certain that the animals can generate dozens of very similar location pulses, but they can also change their characteristics quite sharply. It is still not clear whether the unique character of each location pulse helps location, or whether

the dolphins tend to generate strictly similar standard pulses, and the differences are only defects.

The acoustic high-speed machine-gun of the dolphin shoots out boomeranging pulses. This is the secret code of the cetaceans. They use location pulses to encode questions to their surroundings. Unlike the hunting boomerangs of the Australian aborigenes that return to the hunter if he misses, the boomeranging pulses return to the dolphin only if it hits a target. They return enriched with information about the ambient world. The animal has to do a lot of work to trap the echoes, collect them and filter away the unnecessary ballast. This work is like that of a gold-diggers, who wash tonnes of rock to find gold dust. Hence a dolphin's sonar has another and still more important part, namely, a receiving-analyzing device.

Imprisoned Wave

HOW TO ASK QUESTIONS

Anyone who is always dealing with land animals can recount many interesting stories about their four-legged friends. It is a pity that animals are speechless. If they had the gift of speech, we would learn much more about them. Meanwhile we can only guess about the most common things, i.e. what they see, hear, or which smells the animals sense.

It is quite natural that scientists leave aside guesswork. They need exact data and know how to obtain them. Scientists learned a long time ago how to ask the animals questions and receive answers from them.

Modern science has a large number of ways of examining the functions of the organs of sense, or, as they are called by physiologists, animal-analyzers. The most direct and ob-

vious method is to observe the appropriate reflex. The external sensors, i.e. the eyes, ears, and nose, continuously inform the brain about everything that is occurring around it. The brain analyzes the information, evaluates it and keeps it in memory for some time. While nothing significant occurs around, the animal tends to its own affairs, searches for food, basks in the sun, or simply sleeps. If suddenly something unexpected happens, an unknown sound or smell is sensed, the brain will not tolerate indefinite information and will immediately send an order to its external sensors to orientate themselves, i.e. acquire additional information in order to determine what had happened. It is not without reason that the orientation reflex is called the "What is it?" reflex. On receiving the order from the brain, the eyes, ears and nose immediately turn toward the direction of the unknown signal. Everyone could observe this response in animals.

The orientation reflex is not exhausted by the responses stated earlier. As unknown stimulus can be a herald of danger, or (and this is of no minor importance) a signal of an approaching prey. It is necessary to be on the alert in both cases, to be ready for action. Hence, the orientation reflex is accompanied by an increased secretion of certain hormones, a change in the work of the heart, respiratory organs, vascular tension. Scientists have many ways of evaluating the orientation reflex, but not all of them are convenient to use.

Scientists do not rely very much on ear movements because it is possible to listen to something without moving them.

The orientation reflex has a profound drawback: it attenuates rapidly. The ears of a fox will be on the alert when they perceive a new sound. The animal will begin to sniff around, look around attentively, and listen carefully. If it seems that the sound is not manifesting anything sudden, either danger or food, and if the same sound is repeated a

second, third, and fourth time and still nothing exceptional follows, then the fox will stop worrying. Each time its ears will go to the alert more slowly, and its nose and eyes will work less actively. Finally, after the fifth, eighth, or tenth sound the fox will stop responding entirely. It is unnecessary to spend energy if the stimulus is not bringing in useful information. Hence, data on the orientation reflex are rarely considered in laboratories because the conclusions are too unreliable.

Thus, the orientation reflex is no good for a thorough discussion with an animal. The best type of dialogue is to induce a conditioned reflex in the animal. A conditioned reflex to a sound stimulus is trained in a dog to determine the sounds it hears. Suppose, for example, a researcher wishes to know whether a dog can hear a 500 Hz sound. He places the experimental animal in a sound-proof chamber so that it would not be distracted by other stimuli, the researcher switches on the required sound for 20-30 s and then feeds the animal with a small portion of powdered meat and dried bread. While the dog is licking clean the bowl with the reward, a special device records on paper tape each drop of saliva that is discharged from the dog's perotid gland. After the process has been repeated a number of times the sound signal alone causes the dog to salivate before the edible reward appears. This proves convincingly that the dog hears the sound signal. It is now possible to decrease gradually the sound's intensity (but not forgetting to reward the dog), and we'll learn how weak a sound the dog can perceive.

A differentiation reflex is induced in the dog if the problem is set to determine how finely the dog can discriminate between sound stimuli. Continuing to treat the dog each time the familiar 500 Hz sound is turned on, another sound is engaged from time to time. This new sound is quite unlike the usual one, for example, an 800 Hz sound, but it is never accompanied with food.

The dog will very soon notice that the higher pitched sound is never accompanied with food and salivation will not occur. There is no doubt now that the dog can differentiate between 500 and 800 Hz sounds. The effect of closer stimuli can then be tested, i.e. a 700 Hz sound is used without a reward. It is of no trouble if certain salivation occurs during the initial tests. With patience the dog will understand and salivation will not occur for nothing. Later one can test a 600 Hz sounds, then 550 Hz, and even 520 Hz.

It is not an easy job to collect saliva from some animals. Another method is used in this case. A rat on approaching a fork in a narrow corridor will turn to where it hears a 500 Hz sound, if this means breakfast. It will not even peep down the road where a 600 Hz sound is audible.

It is necessary to know how to ask a question if one wishes to receive an answer from an animal. There is no sense in asking which sounds an animal can hear. It is necessary to ask whether it hears a given sound and can discriminate this sound from another definite sound. The questions should be formulated so that the answers are either "yes" or "no". By inducing conditioned reflexes, or sometimes systems of conditioned reflexes, scientists seek answers from the animals in response to the questions they are interested in. If a conditioned reflex is induced in an animal in response to a certain sound, and if nearby sounds do not stimulate the reflex, it can be assured that the animal hears this sound and distinguishes it from all the other stimuli. Thus, conditioned reflexes are the most widespread way of conducting a dialogue with animals, including the inhabitants of seaquariums and experimental ponds.

ALL THAT OCCURS IN THE WORLD ...

Many of the events occurring around us are beyond our vision, hearing, or smell. The human cannot see X-rays, while an insensible photographic plate does "notice" them. We don't sense radioactive irradiation, we lack receptors capable

of evaluating atmospheric pressure, or polarization of light beams. People observed a long time ago that dogs heard much better than human beings and sensed smells that were inaccessible to humans, while the vision of most predatory birds excels human vision. Imagine, Homo sapiens, the greatest creation of nature, is far from perfect!

Possessing sensitive receptors, animals do not obtain comprehensive information on the environment. They see, hear and smell what they need to sense. The acoustic receptors in the wings of moths only perceive the ultrasound signals that are radiated by the bats hunting them, while lower frequencies are entirely inaccessible for them. A rabbit can sense 24 primary smells, a dog, evidently, senses 35, and a human can only sense 7 to 14. However, this makes it possible for a man with a refined sense of smell to remember and recognize about 10.000 complex smells. Scientists do not know how many complex smells a rabit or a dog can remember. It is possible that animals only partially exploit their faculties.

Investigation of the analysing systems of animals is complicated and difficult, especially when the phenomena being examined are inaccessible directly by our sense organs. This is the reason for numerous failures. Quite frequently the conclusions of different scientists are in disagreement. Everyone hopes that he or she has managed finally to solve the investigated problems. However, it is impossible to predict which scientist will be successful, how much it will cost, and how much time will be required to obtain a comprehensive result. More often it is impossible to predict even approximately the results of the investigation.

It turned out that it was rather difficult to examine even such a simple problem as the hearing of a dolphin. It was not long ago that scientists argued as to whether dolphins actually heard anything at all, and if they did, then where. Did they hear under the water surface or when they pushed their heads above the surface? It is widely known today

that the animals perceive acoustic vibrations both in the water and in the open air. The elaboration of echosounders has confirmed that animals also perceive ultrasounds: they swim away from a vessel when the echosounder starts to operate.

The first research on the hearing of dophins was carried out in America soon after the war. A hydrophone was submerged into a pond with ten bottle-nosed and two long-beaked dolphins. Every now and then the scientists switched on the sound for 2-3 seconds and carefully watched the appearance of the orientation reflex. If at least one of the animals was startled, stopped moving or turned its head toward the hydrophone at the moment of transmission, or tried to swim away, it meant that the dolphins heard the sound. As a result of systematic observations, the scientists came to the conclusion that the dolphins heard sounds well in the range from 100 Hz to 80 kHz.

Two groups of American scientists decided several years later to check the result again. They employed the method of conditioned reflexes when experimenting on bottle-nosed dolphins. The dolphins were trained to approach the researchers when they heard any sound and were rewarded with a fish for their diligence. One group determined that their animal never missed sounds in the range from 150 Hz to 120 kHz. They heard sounds above 120 kHz much worse, while signals of 150 kHz were only perceived occasionally. The other group concluded that the animals responded to sounds between 20 and 100 kHz, while signals of 150 kHz were only observed if their intensity was increased.

A fourth group of American scientists, who also examined the hearing of dolphins, implanted electrodes into the brains of striped rough-toothed dolphins and observed the electric response in their brains to acoustic stimuli. It appeared that the animals heard poorly in the 10-20 kHz range. They perceived better sounds with a frequency from 20 to 70 kHz and then the sensitivity of the hearing worsened badly. The

highest sounds the dolphins could sense were in the 120-140 kHz range.

The given results indicate that the boundaries of optimum sensitivity of hearing in dolphins are somewhere in the middle of the perceived frequency range. It is difficult to give upper boundaries.

Some scientists have mentioned 300 and 500 kHz, but these are quite likely errors of research.

Soviet researchers have investigated the hearing of common dolphins and the porpoises of the Azov Sea. The common dolphin was a record-holder. It is assumed that this dolphin hears sounds between 10 Hz and 320 kHz! Azov porpoises can only hear 3-190 kHz sounds, and they perceive ultrasound vibrations with a frequency of 128 kHz best of all.

A little is also known about the hearing of other dolphins. The Amazon river dolphin perceives signals from 1 to 105 kHz. They hear best signals with frequencies between 75 and 90 kHz. The killer whale has a narrower range of acoustic perception—between 15 and 32 kHz. Evidently, this is associated with their hunting habits. Lower sounds attenuate less, thereby permitting this hungry killer whale to locate its prey from afar. Practically nothing is known for certain about the hearing of sperm whales and the big baleen whales. Some evidence is available from whalers about changes in their behaviour associated with sounds which frighten the giants. This information cannot be relied upon because the sounds were never specified accurately. No matter how simple this question might seem to be, it is necessary to state that scientists have not found a method to make the oceanic giants, i.e. the blue whale, the common rorqual, or other whales, disclose their secrets.

WHAT DOES A HARE NEED LONG EARS FOR?

The question about the hare's long ears will seem naive to anyone who has had enough patience to observe how a

dog pricks up its ears on hearing an unknown sound, or how a horse turns its ears anxiously. Many animals with good hearing have large mobile helices. Even champions in hearing among birds, i.e. owls and eagle owls have had to develop a special structure of feathers and down imitating a helix.

Nature is a thrifty designer. Having designed a horn to trap acoustic waves, it tried to derive as much benefit from it as possible. The problem of superheating is extremely acute for animals inhabiting tropical regions, and the helices have also assumed the function of cooling devices.

Little, attractive fennec foxes inhabit the central part of the Sahara and the Arabian deserts. About four to five young are born in burrows in early spring. If those living in oases are lucky enough to find some fennec foxes, they dig out the burrow and take home the whelps with tiny tails and little round ears. The little animals rapidly gain weight, but their ears grow still faster. When the animals are big enough to be cooked for dinner (they are not kept for amusement), they consist mainly of ears, as was noted wittily by the American physiologist K. Schmidt-Nielsen.

Many comparatively small animals inhabiting deserts have big ears. This makes them very conspicuous, especially when comparing them with their relatives in the temperate or northern regions. The big-eared hedgehog which inhabits the southern regions of the USSR (from the Stavropol district to the deserts of Central Asia), has much bigger helices than its northern relatives. The red-sided hare, which is widespread in Africa from the Cape of Good Hope up to Algeria, has ears that are far longer than those of our mountain or European hares. Another African hare, i.e. the rock hare, has still longer ears. The hares of Northern America, i.e. the dark-brown and the Mexican hares, are quite long-eared. The ears of the Californian hare, which does not inhabit the hottest regions of the globe, are not very long but extremely wide. The American hare, which is called the

leather rabbit, is exceptionally long-eared. Its ears are bigger than the animal itself.

Elephants have the biggest ears among giant animals. African elephants like to wander in the dry hot savanna and like the smaller creatures are also interested in handy aids for cooling their organisms.

For a long time scientists could not understand why desert animals had large ears. It would have been logical to assume that the large ears, by increasing the area of the skin surface, would contribute to superheating of animals. However, things turned out to be quite different. All the creatures we have mentioned except the elephants, can subsist without water. They receive the required amount of moisture with their food, i.e. green plants, roots and fruits, or insects, lizards, small birds and mammals. Hence, they are very economical with water. They cannot sweat in order to cool their bodies by evaporating water like most mammals do. So how do they save themselves from the heat? In the daytime the animals stay in the shade of dry bunches of grass, bushes, stones or rocks. If there is no wind, the temperature of the air and the soil in the shade is slightly lower than in the sun. The ears having an abundant number of vessels and covered with a rare hairy integument, especially on the inside which lack reliable thermal insulation, give off by radiation, first of all to the palate and to the surrounding objects, the heat accumulated in the body. After all the temperature of the northern sector of the sky over the desert is not more than +13 °C even at noon *. Radiation exchange permits the animal to liberate excessive heat quite easily,

---

* Radiation is the emission of energy by a body into space in the form of electromagnetic waves. In the case of heat radiation that may occur even at low temperatures invisible waves of great length are emitted. Radiation is frequently measured using devices that transform the radiant energy into thermal. The radiant energy emitted by the northern sector of the sky over the desert, is not above 13 °C when transformed into thermal energy.

and the helices are the radiators. This is the reason for the long ears.

Thermoregulation is only an auxiliary function of the ears, the main one is certainly hearing. The helices are the first in the series of structures for intercepting the acoustic wave and analysing the information transmitted in it. The helices of mammals are shaped like a funnel. This funnel-like trap ensures better sensing of acoustic waves coming from a definite direction. The ears of dogs, cats, horses, and antelopes are very mobile, i.e. they can turn toward the acoustic wave, a source of sound. As a result, the animals do away with disturbances and can hear weak remote sounds even better than those nearby and loud.

The human ear has lost its active mobility when searching for sound sources and even the ears of the anthropoid apes are relatively immobile. However, it would be an error to think that the ears are useless and are only a doubtful decoration of a human head. The effectiveness of the helix as a funnel for collecting acoustic wave energy is still not quite clear, but its participation in determining the direction of a sound is beyond any doubt. It is very easy to see this oneself. Try to change the shape of the helix, for example, crumble it with your hand, and you will immediately feel that it is more difficult to distinguish the direction of sounds, especially weak ones. The tuberculum auriculae delay the sound, the magnitude of this delay depending on the side it comes from. The brain uses this delay to increase the accuracy of locating the sound source.

The external ear performs one more function. Being a resonator, it intensifies the sound. If the sound frequency is close to the oscillation frequency of the resonator itself, the air pressure in the acoustic meatus, acting on the tympanic membrane, exceeds the pressure of the incoming acoustic wave.

Refined hearing is necessary for sensitive echolocation. It would seem that all the links of the hearing system in

cetaceans should be better developed than those in the other inhabitants of the world. Generally speaking, this is so, but the first link, the trapping funnel, is completely absent in cetaceans. It is useless to look even for rudiments of ears on the smooth shining skin of dolphins. There are none. When examining carefully the head of a bottle-nosed dolphin, it is possible to detect a tiny hole of 1-2 mm diameter on each side. These holes, as everything else on the dolphin's head, are asymmetric. One hole is closer to the nose than the other. They are the beginning of the acoustic meatuses.

The acoustic meatus is never so narrow in land animals with good hearing. It narrows sharply immediately behind the external hole and becomes extremely thin slot with a gap of 360×36 μm, while in white-sided dolphins it is 330×32 μm. A little further on the meatus closes up entirely and turns into a thin cord. The cord runs through a thick adipose layer and reaches the muscles where a gap appears again. The latter is filled with air and is even wider than at the beginning (in bottle-nosed dolphins it is $2250\times$ $\times1305$ μm, and in white-sided dolphins it is 1620×810 μm). Nevertheless, it is hard to believe that this device has anything to do with the perception of sounds.

The lack of the acoustic meatus is associated with the life in the ocean. If it connected the tympanic membrane with its surrounding, as is usual in land animals, the dolphins would constantly be in danger. When submerging, the pressure increases approximately by 1 atm every 10 m. All mammals possess means to even the pressure behind the tympanic membrane, but aqualungers know that this mechanism is unreliable and it fails in the presence of a slight cold. If this happens the tympanic membrane would be broken at the first attempt of diving. The enormous external pressure would easily crush the thin obstacle if it does not meet an equal internal resistance. Thus, the middle ear of a dolphin is covered with skin, a thick adipose layer and muscles, and

does not communicate at all with the surrounding media. Many investigations have been carried out to detect an acoustic line that would permit acoustic waves to reach the sound-sensing receptors. However, the problem has not been solved yet and it causes heated discussions.

THE ENTRANCE TO THE LABYRINTH

One of the seven miracles of the world was the labyrinth of King Minos. All the known labyrinths are famous for being much easier to enter than to leave, but a dolphin's head is like a double labyrinth because it is just as difficult to enter as to leave. Many well-known physiologists regarded it unthinkable that acoustic waves could pass through the skin and blubber and reach the middle ear, which is hidden in a special bone—a bulla—separated by layers of acoustic insulation, i.e. muscles, vessels and sinuses with a protein-air emulsion.

The search for the acoustic door only started after echolocation in dolphins was established. The knife of the anatomist found nothing resembling a passage for acoustic waves. It was necessary to reverse to the idea of acoustic meatuses and check experimentally whether the sounds could run along this passage. The ear inlets of the dolphin were closed with suction cups and the animal was let out into a pool with turbid water. It seemed to the researchers that the suction cup would be a serious obstacle for the acoustic waves, but the behaviour of the dolphin remained practically unchanged. The researchers did not know that the acoustic waves, but the behaviour of the dolphin remained practically sing through the skin beyond the limits of the suction cups. The skin and the blubber were not obstacles, and it was not necessary for the acoustic waves to go through the initial sections of the acoustic meatus. Only the final part of the meatus is important because it is the only slot in the anti-acoustic barrier surrounding the middle and inner ear.

The ability of the sound to manage without special doors was later checked experimentally. The researchers made a complicated operation and implanted electrodes into the inner ear structure of a dolphin. By recording electric reactions it was possible to determine whether the acoustic waves reached that point. Fitting a small sound projector to different sections of the skin on the dolphin's head, the scientists learned that the acoustic waves had no need to push through the narrow external orifice in the acoustic meatus. They could pass through the skin and, after travelling through the adipose and other tissues, they could finally reach the inner ear. However, not all the frequencies can pass through the blubber and muscles similarly well.

A search was then made for the path that was specially designed for sounds. The mandible was suspected. The long bones of a dolphin's mandible have at their junctions, which by analogy with a human being might tentatively be called a chin, three or four small orifices leading to the internal bony canal filled with fat. It is supposed that sounds easily pass through this waveguide and reach the joint that connects the mandible with the skull. It is a mere trifle now to reach the middle and inner ear. The last section of the path was also found.

More than 70 years ago the German anatomist G. Beningnaus found a fatty cord, running from the mandible directly to the bulla. It was necessary then to check whether the dolphins heard anything if the sound was prevented from entering the mandible bones. Polyethylene bags, inflated with air, were used as acoustic insulation. The mandible or the lateral parts of the head were blanketed with the bags and then it was checked whether the dolphins heard anything. Each sound was accompanied by an electric shock. The cardiac rhythm of the dolphin was immediately disturbed by surprise, pain or maybe even offence. A defence reflex soon formed. Knowing that it would receive an electric shock, the dolphin shuddered on hearing any

sound, its cardiac rhythm was disturbed before the shock was made. Hence, there could be no doubt that the animals heard sounds.

The researchers spent many days near the bath with the dolphin and came to the conclusion that the acoustic waves reached the inner ear along two paths: along the canal in the mandible, and from the area of the ear orifices. The external acoustic meatuses are the common and more convenient paths for sounds up to 30 kHz, but sounds of greater intensity prefer the mandible. The availability of different paths for sounds of different frequency is explained by the physical features of the passage of sound along each acoustic path.

HOLY OF HOLIES

The speed and safety of traffic depend on the state of the roads. Sound is quite another affair. Its "transportation" does not require special roads having a smooth hard surface without pits or bumps. Acoustic waves propagate without wheels. The higher the resilience of the medium, the higher the speed of the waves, and the less the loss of energy. Acoustic waves can manage without special roads, but they may need doors to move from one space to another. The energy losses are enormous at the boundary between two media. Only part of the energy of the acoustic waves passes into a new medium, while the other, which frequently is much greater, is reflected from the surface. This is why the external ear of a land animal reminds a funnel full of air. Following the air cone, the acoustic wave reaches the first link of the sound-perceiving system, i.e. the tympanic membrane. Many of the tissues in the head are also perfect sound conductors. The air waveguide to the middle ear is only necessary because it is difficult for the acoustic waves to permeate through the skin from the air. It is different with aquatic animals. The skin and blubber of dolphins are close to those of water by their acoustic characteristics. Hence, permeation

of the acoustic waves into the tissues of the head from the water occurs without any essential losses. Blubber is acoustically transparent. The external ear and the special canal, i.e. the waveguide or the sound path, are not only unnecessary for the dolphin, but they might even worsen the perception of sounds. The changes in the first link of the sound-perceiving apparatus occurred when the dolphin's ancestors migrated to the ocean and new conditions of existence appeared.

The sound-perceiving cells are hidden in all vertebrates in a special formation, called a labyrinth. It is inside the temporal bone in mammals. The bony part of the labyrinth consists of three interconnected semicircular canals, the spiral canal of the cochlea, making two and half turns, and several distensions. The membranous labyrinth, the holy of holies, is inside the auditory apparatus. It is the inner ear and the organ of equilibrium. The pressure vibrations are transformed here into a series of bioelectric pulses transmitted to the brain along the shortest nervous path, i.e. the auditory nerve.

The internal twisted canal of the cochlea is divided by two septa, which run along it, into three independent canals that are filled with different fluids. One septum, which is called the main membrane, is located at the entrance to the cochlea. It is dense and narrow, being only 0.04 mm wide. When it approaches the apex, it becomes more elastic and 10-12 times wider. This is the most significant part of the auditory apparatus, i.e. it is the Corti's organ. It consists of several layers of sensitive hair cells. Corti's organ senses the rapid and very slight vibrations of the pressure. Compressions of the medium and subsequent instantaneous pressure drops in the funnel of your external ear act on the tympanic membrane. Its vibrations are transmitted through a chain of auditory ossicles to the oval window of the labyrinth, and then to the labyrinth fluid. The motion of the fluid initiates a running wave in the main membrane. As it moves along

the membrane, the wave amplitude increases and having reached a maximum begins to attenuate rapidly. The lower the sound causing vibrations of the membrane, the closer the wave will reach the apex of the cochlea. On the contrary, the wave will only travel a small distance in the case of high sounds and, having reached the maximum, will attenuate rapidly. The motion of the membrane makes the hairs of the sensitive cells bend. Acting like microlevers, the hairs excite their own cells which respond with bioelectric pulses. The auditory cell is excited when the tympanic membrane vibrates by 0.0000000006 mm. This is 1.5 times less than the diameter of the tiniest atom, i.e. the hydrogen atom.

People who do not study sensing systems would hardly come to the idea that dolphins should be investigated for some new, unusual means of perceiving sound that could replace the Corti's organ, but scientists are putting all their efforts into such a search. The lack of the external ear in the cetaceans threw the standard concept of the entire auditory system of the dolphins into doubt in the eyes of scientists. Special research was necessary to rehabilitate the notions of middle and inner ear for the animals. Scientists surmised that if the auditory apparatus of the dolphins had been simplified, then it could be considered that its function had deteriorated and it had lost its previous significance. By contrast, if it were possible to reveal changes of an advanced character, the appearance of special means to perceive sound in water, it would be possible to state that its function remained the same. The degree to which the auditory system had adapted to analyze the spatial localization of the sound source would be a good criterion. The auditory system of land mammals is not adapted to work underwater. This is clear to anyone who spent even a minute underwater. A man is unable to localize accurately loud sound sources underwater. Localization is a joint operation of both our ears. An acoustic wave usually enters first the ear nearest to the sound source, and reaches the other ear a little later,

This difference in time is the main source of information about the location of the sound. The diameter of a head is 18 cm on average, and its circumference is 56-58 cm. If you are standing sideways to an arriving acoustic wave, the sound will travel 28 cm to get around the skull to reach the opposite ear. An acoustic wave travels 1 cm in 30 μs, hence, the entire path will require 840 μs. This seems to be very little, but we can notice even smaller differences. When the sound source is only 3° to the right of the body's median line, the sound will reach the left ear only 30 μs later than it reaches the right ear. We can appreciate this difference and discriminate the direction of the sound source with quite good accuracy.

Unfortunately this method can only be used to locate low-frequency sound sources. The auditory system does not simply calculate the time difference of the sound arrival, it also calculates the time difference of arrival of similar phases of the acoustic wave. The maximum difference in the arrival of the sound to the second ear may reach 840 μs. Hence, it is necessary that the time of vibration of the acoustic wave (its complete cycle from one maximum pressure to another) should be more than 840 μs. The auditory centres of our brain get confused in the presence of higher sounds with shorter waves (and a shorter cycle). For example, a sound with a frequency of 10,000 Hz arriving at an angle of 55°, needs 450 μs to skirt the head. The duration of the cycle is 100 μs. Consequently, the acoustic wave will run through 4.5 cycles while skirting the head. However, information about 4 complete cycles of the acoustic wave will simply not reach the auditory centres of the brain. These can only deal with a difference of 0.5 cycle and will naturally be unable to discriminate correctly the location of the sound source. Hence, it is only possible to locate a source by the arrival time of a sound with a frequency of 1,300 Hz.

Sound intensity is another source of information. The length of the acoustic waves in case of low-frequency sounds

is much greater than the size of a head, a wavelength being 3.3 m at 100 Hz. This wave skirts the head quite easily. The situation is different if the wave is short. The wavelength is only 3.3 cm if the sound frequency is 10,000 Hz. These sounds are reflected from the head, and the second and more distant ear is in the acoustic "shade". The sound will reach it but its intensity will be considerably weaker. If the sound source is at an angle of 15°, the difference in intensity will be 150% for a sound of 1,000 Hz, and 900% at a frequency of 15,000 Hz. In case of sounds with frequencies of 3,000-4,000 Hz the difference in intensity is sufficiently great to localize the source.

Nature has given animals many other mechanisms to facilitate the localization of sounds. The mobile ears of an antelope or a goat will turn until the sound is the loudest. The position of the ears will then correspond to the direction of the sound. In some animals one ear moves independently of the other, enabling them to localize two sound sources simultaneously and watch their displacement. It is necessary to turn the head and use both ears simultaneously to localize weak sounds. The mechanism of convergence (bringing the ears together) is then used. This is to a certain extent like ocular convergence, which is used to determine how distant an object appears. This helps an animal to find out where the noise maker is. Many insects use hairs and antennae to localize sounds. The acoustic wave deflects them in a direction opposite to the sound source.

Being able to localize a sound source helps you in a crowd or at a banquet when you are talking with a friend sitting some distance away, speaking, so to say, over the heads of your neighbours, and hearing just his voice, whilst not hearing the people next to you. It appears that we can select a sound source and, leaving aside all the rest, listen only to it. Record the speech of a friend on a tape recorder in a room where several people are talking, and you will hardly be able to understand the recording. Ordinary micro-

phones cannot selectively pick up sound. The magnetic tape will record the voices of all the people, their coughing, the noise of their movements, and the voice of your friend will be drowned in these interfering sounds.

The first complication for a human being in locating the direction of a sound in water is the 4.5-fold increase in speed of its propagation. The time it takes the sound to reach one ear will be correspondingly 4.5-fold shorter as compared with the other. The auditory centres of the human brain calculate the direction of the sound source automatically and will not make any corrections due to the fact that their owner has entered another medium. It is quite possible that they receive no information on this point. It is evidently not planned for. Our life is closely associated with the air medium, and hence a comparison of the time it takes a sound to arrive at right and left ears underwater is useless for localizing the source.

The body's tissues, even its bones, are much closer acoustically to water than they are to air. Acoustic waves reaching a human head submerged in water are reflected from it more weakly than in air. It is unnecessary for the acoustic wave to skirt the head submerged in the water. Travelling along the bones of the skull it reaches the holy of the holies of the auditory analyzer, i.e. the inner ear. The sound will not be noticeably attenuated and the effect of sound masking will be lacking. A head in water is acoustically transparent and will not cast an acoustic shade. Thus both mechanisms, used by land animals to localize a sound source will not operate underwater.

Cetaceans are free of these difficulties. Nature discovered a brilliant solution of the problem, as it polished and perfected whale auditory system over the millennia. The middle and inner ears of the dolphins are not mounted into a bony skull, as is the case in all land animals. The sound-detecting devices in the form of individual formations called bullae, which are immured in a peculiar and extremely hard

bony substance, are suspended from the skull on special tendinous ligaments. For greater reliability the bulla is separated from the rest of the skull by special cavities filled with air or a protein emulsion foam. Communication between the skull and the auditory bone in baleen whales, primarily in finback whales, is not significant though it does exist. However, a special acoustic insulation prevents transfer of the sound from the skull to the bulla. The sound detectors in the right and left ears, being completely independent of one another, are perfectly adapted for localizing the sound source. If engineers were requested to redesign the inner ear of a modern land vertebrates so that the latter could use it underwater they would undoubtedly do it in a similar way.

Scientists carried out special research on the capacity of a dolphin to determine the direction of a sound. Bottlenosed dolphins locate perfectly where a fish, a shot or a water droplet had been dropped by the sound of the splash. They can recognize from a distance of 11-15 m which of two hydrophones, spaced at 25 cm apart, is transmitting an acoustic signal. The animals can localize the source of a noise with an accuracy up to 1-1.5°, and in case of pure tones up to 0.5°.

Nature had to do precise calculations to ensure reliable operation of the dolphin's auditory analyzer. Like any other solid body a bulla with the enclosed inner ear resonates to sounds of a certain frequency. The frequency depends on the size and method of securing the ear. The greater the mass of the object, the lower the sounds that will induce resonance, but the more rigidly it is secured, the higher the sounds needed for resonance. It is obvious that the natural oscillations of the detecting device will introduce considerable interference and impede the perception of sounds. Obviously, nature weighed up different ear bones for a long time, tried different ways of suspending them until an optimum version was found. The weight of the bulla and the

rigidity of fastening are so balanced in modern dolphins that sounds which interest the animals cause no resonance in the bulla.

The design of the dolphin's auditory apparatus sets many riddles to the scientists. The transparency of the body tissues to the acoustic waves, the lack of helices, the very narrow entrance to the otic canal, and its complete closure somewhere midway from the sound detector created another false assumption that the dolphin did not need the middle ear. Scientists assumed that the sound went directly into the inner ear of the dolphin, passing freely through the walls of the bony case, unlike land animals in which acoustic vibrations are only transmitted via the oval window.

The solution of scientific problems requires time. It is clear today that dolphins are not different in this respect from land animals and also require a middle ear. It is of the usual design. However, bones of the lever device which transmit sound pressure from the tympanic membrane to the oval window of the inner ear, have fused together. But this will not disturb their operation. Evidently, the acoustic wave enters the internal ear via the "door" of the tympanic membrane. A different path would be of no advantage because the middle ear performs the function of an amplifier. A 100 to 150-fold amplification is ensured because the area of the tympanic membrane is 90 times greater than that of the stirrup base which presses on the oval window. The system of bones which transmits the pressure also assists in amplifying the acoustic vibrations, though their amplitude simultaneously decreases 60 times.

The inner ear of cetaceans is of the same design as that of other mammals. A dolphin's cochlea is quite large containing one or two turns. It is immediately clear that hearing is important for them. The low-elastic rigidly fixed membrane of the Corti's organ indicates that the dolphin's ear has been adapted for very high sounds. The number of sound detectors, i.e. hair cells, reaches 17,000-18,000. A human

being has approximately the same number. This permits to discriminate the sound pitch quite accurately. But the number of ganglion cells a dolphin has is several times greater than in a human, that permits to perform primary processing of the acoustic information on the spot. The processing ends in the brain in the subcortical auditory centres, which are larger and better developed in cetaceans than in other mammals. However, this cannot be said about the final link in the acoustic localizer, i.e. the temporal cortex and it is not remarkable in dolphins in any respect. Nature has given cetaceans a large and well-designed brain but has not cared for its most significant top sections. Obviously the large hemispheres of dolphins have not yet ripened completely to comprehend fully the information transmitted by their echolocator.

PATENT RETRIEVAL

Fires are a disaster. Mankind is constantly striving to improve system of fire protection. There was once, long ago, a chief of Kiev city police called Rovinsky, who was so worried by the loss of property in his city that he invented a new method of fighting fires. He ordered that the city's firemen arrive at the site of a fire 15 minutes before it started and so could put it out before it could damage anything.

Scientists all over the world have acted like Rovinsky for many years. They thought that a man endowed with God-given reason could invent something that nature had not been able to do in millions of years. They have naively considered that they were always ahead of nature by at least several million years and that this gap would increase continuously in the future.

Nature has made innumerable inventions and rationalization proposals during its three billion years of existence. Mankind has only used some of the patents already taken out by nature but nature jealously protects its professional

secrets. Over the centuries scientists and engineers of our globe quite independently of nature have repeated its patents. After applying echolocation for measuring the ocean depths, they noticed that living organisms know how to do it too.

The process of recognizing the superiority of nature was a hard one. Scientists could not believe that an invention that was born out of pain and that required all their talent, experience and knowledge, accumulated for centuries, was simply made by nature by trial-and-error method. We have only gradually become accustomed to the superiority of nature. And then bionics appeared, a science called upon to retrieve the patents of nature so as to save the scientists from efforts and time spent when repeating an invention made a long time before. It is not necessary to convince bionics experts of the talents of nature. But they go to the other extreme and they see its superiority in everything. They are ready to believe that there is for any invention an analogue in any more or less suitable creature.

Holography is one of the major inventions made after the war in the field of optics. This term is Greek in origin. The Greek word "halos" means "all" while "gramma" means "recording", "description". All together it means "total recording", or "total description".

From its very outset mankind has dreamed of finding a method of saving images of the world around for future generations. As a result, they made drawings on rocks several dozen millenia ago, laying down the fundamentals of modern paintings, and photography appeared at the end of the last century. Nevertheless, none of these methods produced complete images of the object. A photograph and a picture are a chaos of coloured black-and-white spots. They contain so little information about the object that our brain recognizes it only using imagination and the information it has on the ambient world accumulated in its memory.

We see around us something different than that fixed on a photographic plate. The ambient world is three-dimensional, while a photograph produces a flat image. This is because only some of the light beams reflected from the object reach the plate. As a result a photograph produces a scanty picture. In reality all the space around an object is filled with reflected light waves. To obtain the whole image of the object it is necessary that all these light waves, or as professionals say the wave field, be fixed without considerable losses.

D. Gabor, a British physicist, invented a method to simplify and photograph the wave field. Common light sources, for example, a candle, a burning splinter, a luminescent lamp, or the sun produce a mixture of waves with different wavelengths. To illuminate the object being photographed Gabor selected a point source of monochromatic light, which emits waves with the same wavelength. Then, having mixed the beams reflected from the object with the beams coming from the source, he directed them onto a photographic film. The image of the object was not recorded. It imprinted the wave field, which is a set of diffuse irregular lines. When two beams of light were aligned their waves interfered. When the phases of the two waves were the same the amplitude of the summary wave increased (the intensity of the light was large), and hence dark patches appeared on the plate, the amplitude decreased sharply (the intensity was low) if the phases were opposite, and white spots were observed on the plate.

Gabor was not particular successful. He had no sources that could produce sufficiently monochromatic light. U. Denisyuk, a corresponding member of the USSR Academy of Science (he was awarded the Lenin Prize in 1970 for his work on holography) decided to use a laser beam to create the wave field, and a photographic plate with a high-sensitive emulsion. The wave field was thus fixed in three-dimensional space instead of on a flat surface. Semitransparent

reflecting layers appeared in the thickness of the emulsion after developing. By illuminating this plate with the same laser beam, some of the light beams, depending on the density of the plate, stuck in it, and the beams that propagated through the plate are deflected in the same direction in which they had first arrived. In other words, the photographic plate reproduces the beams reflected from the object and its image appears behind the plate. Holographic recording is so total that it is possible to turn the plate, thereby turning the image and observe the object from the side.

The holographic process reminds echolocator. The object the researcher is interested in is illuminated with light beams, and then the change of these beams reflected from the object is fixed. Cetaceans behave in the same way, the only difference being that they illuminate the object with acoustic beams. The analogy is natural. Only one more item is necessary to make up a complete picture, i.e. the availability of a sound-sensitive plate in the dolphin. Experts in bionics considered that the holographic principle of analyzing echo would be proved convincingly if an appropriate receptor was discovered.

G. Dreyer, an American anatomist, was the first to mention dolphin holography. When studying the structure of a dolphin's skin under strong magnification he observed a mass of microscopic papillae that were tightly compressed together in the forehead protuberance. Dreyer decided that these were the stated receptors. It ought to be mentioned straightaway that he had no grounds for this assumption. However, if the papillae were receptors, one square millimeter of receptor surface would have been sufficient to "see" 100 lines. This is very much. The resolution of the most modern TV screens is much lower. Without trying to check, Dreyer announced that the skin on the forehead protuberance was a holographic grating, and the dolphin was attributed the ability of perceiving sounds reflected from underwater objects holographically and plotting a volumetric image

of the ambient world in its brain. It is necessary to mention that this process would require the hypothetical skin papillae not only to perceive acoustic pressure but also to analyze its phase of vibration. Nevertheless, many researchers had grave doubts even that they existed. Despite the attractiveness of discovering an expert holographist in the reigns of Neptune's realm, the Dreyer's theory ought to be recognized as fantasy, whether or not some scientists liked it. Dreyer is mentioned in all the fundamental books published in recent years on the echolocation of dolphins. The reason for the creation of such legends by Western biologists is quite evident. They strive to attract universal attention in order to knock out additional financing from industrialists and different funds to continue their research.

Soviet researchers paid a great attention to the structure of the dolphin's skin. Zoologists thoroughly investigated its receptors, including those on the forehead protuberance. They did not find any skin papillae though they didn't really believe they would. But they did find quite a few different formations like the usual mechanical receptors of land animals. As is known, human skin and that of our four-legged friends contain a huge number of thermal and tactile sensors. Cetaceans have exceptionally large clusters of these around the mouth, blowhole and on the sides of the forehead fat protuberance. No clusters were found on the other parts of the skin.

Many of the tissues of a dolphin's face are also richer in receptors than the rest of their bodies. The periosteum in the front and upper parts of the skull contains many more receptors than the periosteum at the back of the head. There is nothing surprising about this. Breathing requires the participation of sensitive receptors in order to operate. Surfacing for only a short time, the animal must know precisely when the back of its head with the blowhole appears above the water surface to expire and inhale air. Receptors that are scattered along the edge of the jaw are necessary while

eating. A dolphin catches a fish across the fish's body. It is impossible to swallow it this way because it will stick in its throat. The dolphin tosses the fish up and catches it by the head. This complicated procedure can be performed only if the dolphin possesses precise information about the position of the fish between the animal's jaws.

To ensure reliable operation of their echolocators, whales must make corrections for changes in the temperature and salinity of the water as these have a certain effect on the water's density and consequently on the speed and character of the acoustic waves. Certain receptors are required to do this. Are these the receptors on the sides of the forehead fat protuberance?

If we wanted to speculate, it is possible to imagine many other reasons for the additional number of receptors on the dolphin's face. Studies of them confirmed that dolphins are capable of perceiving vibration and acoustic waves. It is possible that dolphins need to have an idea of the head resistance of the water, or to control the character of the location pulses at the moment the acoustic wave propagates from the fat protuberance into the water. Many things can be imagined but holography was fashionable during the decade ago. It seems to researchers that it is everywhere. It is quite clear why they decided that they were dealing with a peculiar acoustic "retina".

Experts in bionics have proposed another assumption about the "acoustic eye" of the dolphins. According to this assumption, dolphins like the mythological Cyclops whom Odysseus had unfortunately met, have a single giant eye in the middle of their foreheads. The role of the lens is performed by the forehead fat cushion, which focuses the acoustic beams on the walls of the air sacs. The receptors there form the "retina of the acoustic eye". It would be very convenient for the animals to consider a foreign object as a whole using such a receiving device. If several dolphins were probing together at the same time, an object

would be better perceived, just like a tree stump in a forest at night, which is seen better if it is illuminated by several searchlights.

Some young experts in bionics went still further. They declared that they believed that dolphins had the "acoustic eye" but considered that it operated holographically. The sound-sensitive "retina" was not the walls of the air sacs, they said, but the brain itself. Hence, the large size of dolphin's brains.

Were there sufficient grounds to assume the availability of the "acoustic eye" or the holographic principle of acoustic vision? I think the latter experts were too much in a hurry. Soviet bioacousticians have rejected this idea completely, having studied thoroughly the possibility of holographic perception of the ambient world by dolphins. The retina of the "acoustic eye" must have a tremendous number of receptors so as not to be weak-sighted. But the skin and the walls of the air sacs have on average about 100 receptors per 1 sq. cm. A retina 10 sq. m in area would thus be necessary to perform sufficiently fine analysis with this density of receptors! The "acoustic eye" would have to be gigantic for another reason too. Whale sonars mainly use locating pulses of 2-5 cm acoustic waves. Compared to light waves these are gigantic and would require an "eye" correspondingly large to use them.

The receiving part of the echosonar must not only record the fact that the acoustic wave has arrived, but also the frequency of the acoustic vibrations. The skin receptors of a human can only perceive vibrations of 200 to 300 Hz. The mechanical receptors of dolphins can evidently perceive ultrasounds too, but it is doubtful whether they can analyze the latter.

The next objection to the existence of an acoustic "retina" is that its site is quite disadvantageous. The forehead is the area where the location pulses are generated. Their intensity is a million times greater than the resultant echo.

In order to perceive the echo the acoustic receptors would have to be very sensitive, and tuned to the perception of very weak sounds. The dolphin's own location pulses would be deafeningly loud, like a gunshot right next to your ear. A human is deafened (albeit for just a few seconds) by a gunshot. Dolphins produce at least 20-40 "gunshots" per second. This continuous cannonade would make it impossible for the animal to use its sound detector as it would simply not be able to recover its operating faculty. Echo also returns 20-40 times a second. The sound generator and the detector must be totally isolated from one another because only then will the sonar operate reliably. In addition, the receptors must continuously "hear" only the frontal resistance of the water, which varies depending on the speed of the animal. The sound detectors are the same mechanical receptors but immeasurably more sensitive.

Thus, neither the skin nor the air sacs can be the receivers of the echosonar. Possibly, as it is assumed by some physiologists, the brain proper listens directly to the continuously arriving echo. It is difficult to consider this theory to be scientifically grounded. It only indicates that its authors are unfamiliar with the mechanisms used by the brain to process the incoming information. Brain analysis is a multistage process. The last stage of analyzing the information supplied to the brain takes place in the cells of the cerebral cortex. The cells themselves like every other nerve cell in the organism, can only respond to an action, whether it be electrical, chemical, or mechanical, by becoming stimulated. They are unable to react to external effects differentially. Every sensitive cell, no matter what it perceives—be it light, sounds, smells, heat, pressure, or strain—in every animal on our globe, from the most primitive ones up to Homo Sapiens, is designed in the same way. It consists of a sensitive villus, consisting of two axial fibrillae and nine bearing fibrillae. The villus proper is the sensitive element. The cells of the brain have nothing in common with the latter and are

unable to perceive echo. Hence, even if we would like to learn holographic acoustic analysis from nature, we are forced to recognize that nature has not patented such inventions. We can rest assured that there is no plagiarism and that the holographic principle of processing the information, which man has invented, infringes no patent.

The reader may consider our patent search to have been inadequate. Indeed, the research is only beginning. Scientists in Kiev are now studying giant whales. They have found in the cachalot a tremendous number of tiny vesiculae ranging in size from that of a pea to that of a pigeon egg. These are arranged on the rear internal wall of the vertical air sac. The vesiculae are very rich in nerves. Having made this interesting discovery, the scientists immediately recalled Dreyer's skin papillae and therefore called this vesicular tissue the cachalot's "retina".

Evidently, the abundance of vesiculae with a large number of nerve cells may provide the required minimum of sensitive elements. However, all the other doubts still remain. In addition, it must be proved that this vesicular tissue is neither the result of an inflammatory process, nor a post-mortem change in the tissues, and that it is present in all sperm whales without exception. This is far from having been achieved, but experts in bionics are rubbing their hands with satisfaction. Their professional enthusiasms tend to make it hard for them to believe that human beings could invent anything independently and without applying anything that has been done earlier by nature.

ASTRIDE THE WAVES

When probing the world around them, the dolphins work very hard. They follow the fate of each location pulse, and this is not easy. A location pulse that has been reflected from an underwater object, has changed so much that even its creator may be easily mistaken and may not recognize

its own echo. But it is the changes in the location pulses that inform the dolphin about what is occurring around it.

Scientists studying echolocation of animals have been interested for a long time in determining the information transmitted by acoustic waves, how much of this information is perceived by the dolphin, and how accurately it can perceive this information. The basic parameters of acoustic waves are their oscillation frequency, amplitude and phase. To form an idea about the frequency of oscillations, it is necessary to estimate time. Mankind has always been interested in measuring time. Priests have known from time immemorial how to measure time accurately. The first special instrument for measuring time, a sundial, was invented in Egypt as far back as 1500 B.C. Sandglasses and water clocks were invented by humans for unit measurements. Clocks with toothed wheels and driven by weights, only appeared some twenty centuries later.

Modern mechanical clock mechanisms are the end result of Galileo's discovery of the isochronal pendulum effect. But Galileo was quite satisfied with a water clock that he tuned so finely that the owners of modern chronometers would envy him. The need for accurate clocks increased greatly with the advance of navigation. The longitude of point on a globe can only be determined by using a chronometer. The first sufficiently reliable instrument was designed quite recently in England in 1751. Clocks, chronometers, and stopwatches have been improved since then and have become amazingly accurate.

The sense of time is highly developed in higher animals. Cetaceans are not an exception. By keeping an accurate chronometer in a "vest pocket" and possessing the ability to follow the fate of their location pulses, dolphins cannot but be "interested" in the time they take to return as an echo. It is not difficult to determine the distance to the object that a location pulse has struck if the speed of sound propagation in water is known.

Scientists devised dozens of special methods to check the accuracy of the dolphin's stopwatch. Indirect methods have been used most frequently. One of them consisted in the following. Two plates arranged in parallel to each other were suspended in a pool with a dolphin. The animal started to investigate them through shear curiosity or natural carefulness, irradiating them with location pulses. Each pulse striking the front plate reflected partially from it. Then it passed through and striking the second plate partially reflected from the latter. Thus, each location pulse returned to the dolphin in the form of a double echo. The greater the spacing between the plates, the longer the interval between the reflected pulses. Having induced an appropriate conditioned reflex in the animal and by altering the spacing between the plates, it is possible to determine the accuracy to which the magnitude of the intervals between the plates is estimated by the animals. If the spacing between the plates is 10 cm, the part of the sound not reflected from the first plate and having passed through it, must cover another 10 cm to the second plate and only then will the second echo appear. However, while this sound is covering the spacing between the two plates, the first echo will also cover 10 cm. Thus, when the spacing between the plates is 10 cm, the distance between the reflected pulses is 20 cm.

Suppose we bring the plates together, assuming that the dolphin can "notice" a difference if the spacing is reduced by 1 cm (i.e. it will be now 9 cm). The second echo will then lag behind the first one by 18 cm, i.e. it will be 2 cm closer. Sound travels 2 cm in sea water in approximately 13 millionths of a second. Such a result would tell an investigator that the animal can use its "stopwatch" to measure time with an accuracy of 0.000013 s.

These experiments did not require any special equipment, not even a stopwatch. The simplicity of the method was so tempting that similar experiments have been conducted in different versions in many countries. I have not given any

results intentionally because the experimentors themselves abandoned the conclusions made on these grounds. The point is that a location pulse striking the plates is reflected and generates natural oscillations. A change in the spacing between the plates alters essentially the parameters of the oscillations. Dolphins certainly perceive the change in the spacing between the plates, but how they do so is obscure. It can be assumed with the same degree of probability that dolphins measure the distance by estimating the time between the arrival of the first and second echoes, and due to the changes in the parameters of the natural oscillations of the plates once located.

Another method of checking the accuracy of the dolphin's "stopwatch" is to make it estimate the magnitude of the interval between two acoustic signals. This experiment is quite complicated because it is difficult to keep their parameters intact without significant alterations when changing the interval between sound pulses. A surprising phenomenon was discovered during the experiment. It turned out that it was easier for the dolphins to estimate very small time intervals, i.e. of the order 0.0001 s, for example, it is easy for them to discriminate an interval of 0.00005 s from an interval of 0.000055 s, than it is for them to analyze longer intervals, of the order of 0.0003 s, while the accuracy of analysing time periods of more than 0.0005 s is quite poor. The experimental data indicated that dolphin's "clocks" run with an accuracy of up to 1-2 millionths of a second.

Another experiment illustrated that the dolphins react to sound pulses only if the intervals were in excess of 0.0005 s. These data were obtained directly from the auditory centers of a dolphin's brain. If the intervals between short acoustic stimuli were too short, bioelectric potentials did not appear in the brain as a result of the second signal. Consequently, dolphins did not perceive them. The second stimulus caused weak electric reactions only when the interval was extended to 0.0005 s.

Frequency is the major parameter of sound. It is important to determine how accurately the animals can discriminate between sounds with slightly differing frequencies. Dolphins surprised the scientists once again. Bottle-nosed dolphins recognized high-frequency sounds with greater accuracy than low-frequency ones. They recognized a difference between the sounds if their frequency differed only by 0.3-0.4%. Sounds lower than 5 kHz were discriminated by the animals worse. The hearing of porpoises is even better. Some scientists consider that they can perceive a change in the sound frequency of even 0.02-0.2%.

It is simpler to discriminate between sounds that are longer in duration than those that are shorter in duration. Shorter sounds are characterized by a complex spectral structures, this depending on the frequency of individual sound pulses. Dolphins discriminate well between sounds that are repeated often. Their spectrum comprises a smaller number of constituents than the spectrum of sounds appearing with large intervals, and having more than ten harmonic components.

The phase is another major parameter of acoustic vibrations. Theoretical calculations have indicated that a phase analysis of the acoustic signals may be beneficial for the animals because it yields additional information and may assist in perceiving a signal masked by other sounds. Engineers started using phase analysis in technical devices long before biologists realized the meaning of the phase of the acoustic wave. It has only recently been discovered that human beings and many animals can discriminate the phase of a signal. This faculty is associated with the fact that a drop in pressure, i.e. the negative phase of acoustic vibration, does not stimulate hair cells in the inner ear. And on the contrary, the positive phase of the acoustic wave, reflecting the moment of maximum pressure, does stimulate them.

It is not known whether dolphins can recognize the initial phase of the signal and whether they need this faculty

for successful echolocation. Experimenters have encountered grave difficulties while investigating this problem. A change in the signal phase is accompanied by a significant variation in its spectrum, and this complicates the research. Every attempt has been made to find out this information, though they have all been unsuccessful. If dolphins are as capable in this respect as they are in others, investigating their echolocation systems might make it possible to design better radar devices. Sadly, these creatures, who are so friendly to humans, are so reluctant when revealing their secrets.

The Black Box

THE EMPEROR'S CLOTHES

A photograph of Gina Lollobrigida in the nude was once on sale in London in 1960. It became known later that the photograph had been taken for a private collection. The actress had been photographed by an infrachromatic camera with a special film sensitive to infra-red rays. The lady's light clothes had thus been no obstacle. Agreeing to pose in front of the lens, she had not suspected what the photographer had intentioned.

The penetrating power of acoustic waves is also quite high, being much greater than that of infra-red rays, but it is not perfect. In order to estimate it, let's recall that sunlight can be detained by a sheet of paper. A thin sheet of metal or even a fine metal grid will detain radio waves. Heat waves will penetrate both paper and metal grid. A lead plate, though not very thick one, is required to stop X-rays. A flux of neutrino, which is a fundamental particle that occurs during the beta-decay of atomic nuclei, or that of other unstable fundamental particles, for example, pi-mesons, can be stopped only by means of a lead plate about 10 trillion kilometers thick! Acoustic waves will be placed on this scale

not exactly in the middle but they are somewhere between X-rays and a neutrino flux. Their wide application for active location is due, on the one hand, to their ability to penetrate a variety of substances, and on the other hand, to their ability to reflect from surfaces that are boundaries between two media. Because of this dolphins can obtain information concerning the far side and inside of an object they are probing as well as information about the near side, the far side and inside being invisible to the eye. The animals can discriminate quite easily between solid objects and others with an internal cavity but which are very similar. Bathing costumes, which trainers put on when they go into the pool with dolphins, are quite transparent to acoustic waves. I don't think dolphins even notice them. They see the swimmers in the "Emperor's clothes". Their location pulses examine our lungs as well as an X-ray unit can, and they can observe the work of a human heart without any additional equipment.

The high penetrating power of acoustic waves permits toothed cetaceans to manage without vision. Neither the blackness of the night, nor turbid waters are obstacles for the echosonar. Particles of dirt and silt rising from the bottom present no obstruction for acoustic waves. Their sound conductivity is close to that of water. The situation is quite different if a large number of tiny air bubbles are suspended in the water. They can absorb acoustic waves completely. Hence, dolphins, being excellent swimmers and having mastered their bodies, avoid approaching coastal cliffs, where the breakers turn the waves into white foam.

The different acoustic transparencies of various materials might be a real complication for efficient location, especially when the transparency of the object is close to that of water. In this case the reflection of the acoustic waves at the boundary between two media (i.e. the water and the object being located) will be negligible and the object will be invisible. Therefore dolphins may not notice fishing nets or other simi-

lar obstacles when their location is interfered with by the presence of acoustic disturbances.

The bodies of fishes conduct acoustic waves quite easily and produce small echoes. It has been calculated that a live mackerel 12-15 cm long and turned with its side to the dolphin can only be detected by the animal at a distance of 12-15 m. It is more difficult to "see" a dead fish. The dolphin can detect it from the tail at a distance of 3.4 m, from the head at 3.8 m, and from the side at 9-10 m. A live fish is more visible because its swimming bladder is full of air. This is the most "visible" part of the fish for a dolphin though it is inside the fish. Experiments using live fish are not very illustrative because it is impossible to make the fish pose for the dolphin in a certain way. Scientists do not know how dolphins detect fish schools. It was necessary to recourse again to calculations. These have indicated that if the location pulse strikes four thousand mackerel, the animals detect the school at least 100 m away, but they will not be able to "see" them at a distance exceeding 500 m.

According to the same calculations, dolphins find each other using echolocators at a distance of 100-130 m. Lungs full of air assist them greatly because the other parts of their bodies produce far weaker echoes. It is quite possible that dolphins "see" each other as if they were in an X-ray picture, i.e. weak contours of the bony skeleton stand out against a background of general outlines, defining the heart, liver and other organs, the lungs being a bright spot in the centre.

During the first years of research on dolphins, the experiments were conducted in a turbid water, at night, or in a darkened pool so that the animals could not use vision to do their location. However, it is very difficult to work under these conditions. Someone then thought of fencing off the objects to be detected by a cloth screen. The animals were quite indifferent toward this innovation. The screen did not

impair the work of their sonar. Cotton fabric is just as transparent in water to acoustic waves as window glass is to sun rays. Experiments carried out in different laboratories have confirmed that dolphin's sonar operates like an X-ray unit. The animals can discriminate easily between a bottle with water and a bottle full of air. If several bottles were lowered into a pool, a dolphin easily found the one with a residual air bubble.

Metal is more transparent to acoustic waves than it is to X-rays. Two brass plates were arranged so that the smaller second one was behind the first one and was not visible from the front. The dolphins easily detected it, they were never at a loss, no matter what tricks the experimenters played. Even when the scientists hid the plates in a plywood box, the animals could determine whether there were one or two plates inside.

We involuntarily lose heart when we compare the organs of senses of a dolphin with those of a human being. It is extremely disappointing that we lack such a versatile device as echolocator. It would be so useful in understanding the surrounding world! Unfortunately, the coin has another side. It would hardly be a pleasure to anyone always to see the skeletons of those close to him and to see their inside. However, aesthetic criteria are quite changeable. It is quite possible that if we had echolocator, we would apply other criteria of female beauty. Instead of admiring the colour of the eyes, the length of the eyelashes and the slimness of the waist, we would pay attention perhaps to bony protuberances on the skull, intricate rib patterns, or particular of the shoulder blades. It is quite possible that dolphins do this when they choose their partners. This is one of the indices of the adaptation of mammals to life in an aquatic medium.

From the End of the Nose to the Tip of the Tail

Human estimation of distance by sight, frequently glorified in characters of literature, beginning with Tiel Ulenspiegel and ending with Leskov's Levsha (left-hander), is quite often bad. Most people don't trust their sight and support their estimates by measuring whenever it is possible.

Human beings have always sought accuracy. Many methods have been developed since ancient times to determine the size and shape of objects that cannot be measured directly. More than 500 years B. C. Pythagoras learned that the Earth was a sphere suspended in space. He was the first to deduce that lunar eclipses were similar to solar ones, but that it was the Earth that shaded the moon and not the moon that shaded the sun. By carefully studying the shade of the Earth, Pythagoras concluded that our planet has the shape of a ball.

Works on determining the dimensions of the planet were just as impressive. At the time of Aristotle mathematicians had attempted to calculate our planet's circumference, but they were in error by about 20,000 kilometres, i.e. almost by a factor of 2. Only 100 years later, Eratosthenes did an enormous amount of work to calculate the radius of the earth in Alexandria at Ptolemy's Museion. He had to make two expeditions to the Rhodes Island and to the city of Siena. Using partially his own measurements and partially relying on the evidence of travellers, he managed to calculate the length of the Alexandrian meridian as 252,000 stadia, achieving an accuracy almost unbelievable for his time. Converting the figures of Eratosthenes into metric system, we find that his value for the circumference of the Earth is 39,500 km and its radius is 6,290 km. The error for the cir-

cumference was 500 km, while that for its axis was even still less, being only 75 km.

The methods he used hardly made it possible for him to have been so accurate. Most likely he used intuition and estimation of distance by sight, like that of Leskov's Levsha, these abilities are endowed sometimes by nature on a few lucky people.

Animals estimate distances by sight. None of them have used auxiliary means, nevertheless they get quite good results. A dolphin's sonar is almost faultless eye. It has been known for a long time that bottle-nosed and common dolphins can discriminate between small fish and larger ones at a distance of 1-3 m. Discrimination was faultless when the larger fish was two times longer than the smaller one.

Fascinated by the dolphin sonar, scientists in different countries have made them discriminate the sizes of balls, cylinders, or slabs. It is not hard to understand why these objects were used in the experiments instead of cubes, bars, prisms or hemispheres. The animals cannot be given strictly fixed objects for discrimination because vibrations will be generated by the location pulses. The acoustic waves generated by the vibration, would be quite complicated and objects would differ so much from one another in terms of their accompanying parameters that the animals would not need to obtain distance estimates of the objects. It is also impossible to suspend such objects on a thin thread, as can be done for balls and cylinders. This is because it is very difficult to make a cube or bar remain suspended in absolutely the same position with relation to the dolphin. Beside that the dolphin cannot be forced to analyze them always from the same point in space. Comparing cubes, suspended by an edge or side, it will hardly gain high accuracy, while balls and cylinders look absolutely the same wherever they are viewed from.

Research on the ability of dolphins to determine the size of objects was started by presenting them flat objects. Foam-

plastic slabs were lowered into a pond with common dolphins. Frequently, even very simple experiments with dolphins do not run well for a long time. The animals could evaluate quite finely many of the properties of objects but they stubbornly did not wish to notice them. If a monkey is given two similar balls, it will first compare their weight. A dog cannot do it though it possesses quite clear ideas about gravity. It was finally "explained" to the common dolphins what was expected of them and it suddenly turned out that it did matter to dolphins what the shape of the slabs was. Square slabs were discriminated with greater accuracy. Locating them from a distance of five metres, the dolphin noticed a difference if the area of one square slab was only 7 % greater than that of the other. It was more difficult for them to estimate the area of triangles. The areas of two triangles had to differ by at least 25 % before dolphins could notice a difference.

Dolphins could determine the size of metal balls with still greater accuracy. In this case the error depended on the material of the balls. Bottle-nosed dolphins discriminated big steel balls with a diameter of about 6 cm with an accuracy of 0.6-1.0 cm from a distance of 1 metre. Lead balls of approximately the same size were discriminated by the dolphins with an accuracy up to 0.5 cm from a distance of 8 metres. Wax balls were discriminated from the same distance four times worse and with an accuracy up to 2 cm. In order to notice the difference between wax balls 5 and 6 cm in diameter the animals had to be 3 metres away.

It was not difficult for the dolphins to distinguish between tiny lead balls 14 and 16 mm in diameter. They were not confused even at a distance of 5 metres, but they could not distinguish between steel balls of approximately the same size.

Many experiments were carried out with cylinders. The animals had to determine their heights. Bottle-nosed dol-

phins and porpoises could appreciate the difference with certainty when it was 10-30%.

The creativity of the scientists led to evermore complicated experiments. The dolphins were steadfast in this contest with the experimenters. It has been found that they were not only capable of discriminating the larger of two or more cylinders from a considerable distance but would not even confuse the figures when they were shown to them in turn. When the difference in the size of the balls, cylinders or slabs was essential, dolphins could accurately estimate the size of an object at quite considerable distances of 17-20 m.

It was also very interesting to learn how accurately the dolphins could determine the distance between two objects. Two identical objects were always used in order not to complicate the task. Most frequently they were balls, or at least cylinders. The experimentors were interested to learn when it was easier for the dolphins to measure the distance between objects: when they were arranged horizontally, vertically, or one closer than the other. If the distance between the horizontally arranged objects was about 1 metre, the dolphins could measure this distance 10-15 m away and with an accuracy of 1.0-1.5 cm. It was more difficult for them to estimate the distance between objects arranged one above the other. In this case their measurements had an accuracy of 1.5-2.5 cm. The dolphins were most accurate when they measured the distance between remotely and closely arranged objects. The error in this case did not exceed 1 cm.

These experimental results were repeatedly checked. The scientists did not believe some of them because it is considered that the resolving power of a sonar cannot exceed the spatial extent of the signal. It is 3 cm for the shortest location signals. Consequently, the dolphins should not be able to distinguish difference in the remoteness of the balls from one another in two pairs if it is less than 1.5 cm. The point is that the location pulse, reaching the closest ball, is reflect-

ed from it, and the echo returns to the dolphin. If the second ball is arranged 1.5 cm behind the first one, then the location pulse will have reached it by the time the echo from the first ball has traveled 1.5 cm back. Consequently, the first echo will be 3 cm ahead of the second one. Hence, the accuracy of the dolphin's measuring instruments should not exceed 1.5 cm.

It is not easy to arrive at the truth. Great Pythagoras sacrificed 100 oxen to Zeus, evidently for assistance in inventing one of the geometrical rules. A scientist ought to remember that even a tiny discrepancy between the results of an experiment and the predictions of the theory should make him watchfull. It may certainly be a simple mistake, inaccuracy of the experiment, but it may also herald a discovery or phenomenon, which is new and unknown.

It is possible to state in this case with certainty that there was no experimental error. The dolphins really notice a 1.5 cm change in the distance between the objects. It is now assumed that they use interference, i.e. the interaction of acoustic waves.

Each of two objects located by the animals creates an acoustic field on reflecting the location pulse. Two acoustic fields from quite closely arranged objects interact with each other. If the phases of the reflected acoustic waves, returning to the dolphin, coincide, they add and the amplitude increases in the summed wave. If the phases are opposite in the interacting waves, they suppress one another and the intensity of the sound drops. Evidently the dolphins notice this change in the intensity of the echo.

This explanation seems quite convincing. It is necessary to know what occurs in the brain of the dolphin. Does the interference of the acoustic fields of the located objects enable it to notice that the distance has changed between them, or can the dolphin estimate these changes quantitatively and continue to make accurate measurements indirectly? If the

last assumption is confirmed, it would mean that the sonar of the dolphin is more perfect than it seems to us to be today.

ONE IMAGE

It is long known that dolphins determine the shape of an object by means of echolocation but nobody knows whether they formulate it as an image.

From the point of view of cybernetics an image is a generalized description of an object. The image we have in our brain helps us recognize an object irrespective of its position in space, variation in illuminating, its size, or colour. We can recognize different objects and classify them because of generalizing effect of one image. A table remains a table for us, no matter whether it is in the room, or in the street, whether it is turned upside down, or loaded on a truck, whether it is white, brown or black, small or big, covered with a table-cloth or an oil-cloth, laid with delicious dishes, or with none, whether it is old and broken, or is new and smells of varnish. We recognize as a table the object we sit at when dining, a small coffee table, or a laboratory desk, a table with one, three, four or any number of legs, a round, triangular or square table, a desk with any number of drawers, or a simple flat platform fixed on a bracket like those in railroad carriages or cabins.

Animals can also formulate visual images, though they are less generalized than human images. This function improves in the process of evolution of the brain. Fishes can memorize quite complex images but any variation will confuse them. A triangle with its sides slightly increased or decreased will remain a triangle for a fish, but it will not recognize a triangle painted a different colour or turned upside down. Gophers and rats can be taught to recognize geometrical figures no matter how they are turned, but they

will not see any similarity between a black circle on a white background and a white circle on a black background.

Monkeys recognize figures quite easily no matter what colour they are painted and which background they have. A chimpanzee can even recognize simple figures by touching. Having looked at a drawing prepared by the experimentor and rummaging briefly in a bag, which it is not permitted to look into, the monkey will find among other things a triangle cut out of thick cardboard. A human being is capable of a more complex form of generalization. A two-year old child shown a triangle made up of individual circles (like a triangle of billiard balls), can recognize a triangle. Even the anthropoid apes cannot solve this problem.

Dolphins easily recognize and don't confuse three-dimensional and plane figures. Scientists in Moscow carried out research on distinguishing plane figures. These were cut out of thick acrylic plastic and covered with a layer of porous rubber, which is a good reflector of acoustic waves. The researchers thought that a material with a high reflective capacity would simplify the problem for the dolphins. After a substantial amount of training the animals learned to recognize from 10-18 m a square with 10×10 cm sides from different triangles, rhombs and circles, having the same 100 sq. cm area. The researchers did not try to determine all the criteria including reflected echoes the animals used. This is illustrated by another experiment.

The animals were trained to distinguish between a $10 \times \times 10$ cm square and 7×7 cm square. When the dolphins unerringly picked the larger square, attempts were made to confuse them by offering a square of the same size but with holes in it. The holes were of a square shape, ranging from 1 to 86 sq. cm in area and placed in the middle. When the hole was of maximum size, the square turned into a 4 mm frame with a small area. When there were two figures, namely, a small square and a large one with a hole, the dolphins picked the figure with the hole more often. It meant

that they could determine the size of a thin frame too, which reflected a very weak echo.

Some observations suggested that it was difficult for the dolphins to notice holes. At any rate, they did not display an aptitude to do this. The same animals were offered to discriminate between a solid square and the one with the same size but with hole. The dolphins solved this problem well if the hole was 25 sq. cm in area. They also did it satisfactorily if the hole area was 6.2 sq. cm, but they never noticed holes with an area of 1 sq. cm. Numerous experiments have shown that the animals can estimate the intensity of an echo with an accuracy of up to 10%. Consequently, a 6 sq. cm hole, which constitutes only 6% of the figure, is noticed with difficulty, if this criterion is used. But dolphins discriminated with confidence figures with holes from solid figures. It means that they use other properties of the echo. Most likely, they use spectral characteristics. When a location pulse is reflected from a solid surface, distortion of the spectrum will occur in a more low-frequency range than if it were reflected from a frame. It remains for scientists to determine whether dolphins notice an attenuation of the echo, a variation in its spectrum, or they really identify the holes?

The use of indirect indications for analyzing the environment is the prerogative not only of dolphins. Humans are also apt to go along side paths when recognizing things. Academician L. Orbely liked a story about his friends who had a four-year old child with a good visual memory. When guests would come, his parents would bring out heap of family photographs and the boy would unerringly named everyone in the photograph. Orbely noticed that the child could as easily recognize the faces as the reverse sides of the photos. It seemed that it was easier for the boy to recognize a reverse side because it had spots, inscriptions, and the stamps of the studios where the photos were developed. The indirect indications were quite convenient. Dolphins use

them on a wide scale. Possibly, they may seem indirect to us. It cannot be ruled out that very unexpected types of information derived from the echo inform the animals about quite definite properties of the echolocated object.

It would be nice to learn the criteria dolphins use in order to find out what a located object is made of. A ball reflects each location pulse of the dolphin as a double echo. The first portion is the real echo, it is the location pulse reflected from the ball. The second part of the echo is created by the natural oscillations of the object being located and it depends on the material and size of the ball. The scientists managed to prove that it was the second part of the echo that helped the dolphins to learn what the ball was made of.

One should not be surprised that scientists cannot explain everything about the way dolphins perceive the environment. Human do not understand many things about their own perception of reality, which frequently is quite whimsical and intricate, for example, the art of abstract artists. A few of the works done by an abstract artist might convince one that his perception is miserably destitute and that he is blind in certain respects. A sculpture of a football that had not scored a goal was exhibited in London not very long ago. Evidently, the human brain can form even these images.

Dolphins can notice many things in their environment by using their sonars, but it will take a long time before we learn what image they form in their large brains.

WHO IS LOUDER?

The trumpets sounded and the city walls of Jericho crumbled into dust! The rich and well fortified city had been captured without a battle. This is how the Bible narrates the fall of Jericho. In our days this ability of acoustic waves would not evoke any surprise. We know that at extremum

values infra- and ultrasounds possess considerable power. Sound can destroy, sound can kill, and it is quite evident that a strong sound can impede the perception of weaker sounds.

The sea is rarely calm and quiet. Heaving and falling the waves roll continuously in an attempt to overtake one another. How much is necessary to muffle the weak echo of the dolphin's location pulses? When the wind intensifies and the ocean begins to roar, the thunder of the waves can muffle every other sounds. Sounds of biological origin, the voices of living creatures are added to the noise of the water. Most of marine inhabitants use ultrasounds in ranges close to that used by dolphins. The unnecessary extra echo also creates interference for the dolphin. The location pulses are repeatedly reflected from the uneven sea surface, from the bottom (if it is shallow), from their companions in the school, from other inhabitants in the sea and from objects in the path of the acoustic wave. This cacophony of sounds can absorb the echo reflected from the object that the dolphin is particularly interested in.

The location pulses proper also impede reception of the required echo. The dolphins send them out in long series of 10-50 per second. The frequency of the pulses can increase considerably. The closer the animal approaches the object it is interested in, the more frequent its location pulses, and when the distance reduces to 40 cm, the frequency of signal generation jumps up to 200 pulses per second and continues to increase if the situation is very complicated for the dolphin. The frequency can reach 525 with bottle-nosed dolphins, 400 with common dolphins, and 600 pulses per second in the case of porpoises. Can a weak echo push through this hail of location pulses? Analysis has indicated that the location pulses do not interfere with the echo. No matter how requent they are, or how small the interval between them, the dolphin will listen to the echo of the preceding pulse before sending the next one.

It is known that when humans and animals are perceiving an acoustic signal and transmitting the corresponding information to the brain, they are distracted for some time from analyzing and perceiving other sounds. The period during which receptivity is absent is considerably shorter for dolphins than for humans. Otherwise the animals would not be able to perceive the echo from the majority of the location pulses it has propagated. Their auditory system is more perfect and they recover the ability to react to acoustic stimuli within 0.5-1 ms. They can perceive up to 2,000 short sounds a second, this being four times more than the number of actually propagated signals. The auditory system of the dolphin has a high safety margin.

Special experiments were carried out to estimate the noise immunity of a dolphin's sonar. A strong noise was transmitted into the water through a hydrodynamic loudspeaker. The dolphin had to locate a tiny object suspended into the pool on a kapron thread. The animal located it at a distance of 8 m. The strong noise did not interfere with the sensitivity of the animal's sonar.

People, who have to talk in noisy shops, at an airport, on the underground or in other words, wherever the noise muffles human speech, begin to speak louder and extend their words. Dolphins do the same: they try to "cry" louder than the noise in the pool. The loudness of the location pulses became so great that their low-frequency elements were clearly audible under the water. The only difference from a human being was that the dolphins didn't increase the duration of the pulses but quite skillfully employed their capacity to "cry" louder than the noise. If it consisted of a limited frequency band, that impeded perception of a certain part of the location pulse, the animals intensified the loudness of just these frequencies. The human's sound-producing apparatus is not capable of such differentiated activity.

Dolphins know another method of fighting noise, which is to alter the pitch of the location pulse. If the noise is limited to a narrow frequency band, the animals can reconstruct the spectral character of the location pulse, making its basic part considerably lower or higher than the acoustic interference. Technically speaking one can say that the dolphins tune out the interference by frequency and it does not bother them.

The dolphins used yet another method of avoiding interference, when a series of noise pulses were supplied to the pool. The animals tuned out in this case with respect to time, by propagating location pulses and perceiving the echo in the intervals between the noise pulses. The latter did not bother the dolphins if the interval between them and the echo was more than 300 μs. The animals managed to analyze what they heard in this brief instant.

Dolphins generate very loud location pulses. If we could hear them, they would seem louder than the roar of plane on the runway of an airport. It would seem that any animal should be deafened by this noise. Scientists could not understand for a long time why the auditory system of dolphins did not suffer from the animal's own noise. This question has only recently been answered.

Interesting experiments have been carried out to determine whether dolphins could orient themselves in a complicated acoustic situation, or whether they were disturbed by interference due to reverberation, i.e. multiple reflection of acoustic waves from various objects in the surroundings that the animals were not interested in at the moment. The researchers reproduced a situation in an experiment that would be close to reality. A circle was laid on the bottom of the pool made up of 300 stones ranging in diameter from 5 to 30 mm. The object the dolphin had to find and recognize was placed in the centre of the circle or suspended above the bottom at different height. The dolphins easily detected a 33 mm steel ball from a distance of 11-15 metres

when the latter was suspended 30 cm above the bottom. But they couldn't notice a ball among the stones on the bottom even from a distance of 5 metres.

Different versions of the experiment illustrated that the animals could detect the ball only when its upper edge would extend 2 cm above the largest stone. In this case dolphins used special methods of searching for the ball. Ordinary location from the upper layers of the water produced no positive results. A steep acoustic beam returned from a rock stream as a multiple echo, and the dolphin could not make out anything in this mishmash. In order to find the ball, the animal dived and located the space, sending location pulses at a small angle to the bottom of the pool. This made it possible to "see" the profile of the stone heap and detect the ball extending above its surface.

Three hydrophones were fixed on the head of the dolphin: one 5 cm in front of its blowhole, the second immediately behind the blowhole, and the third on its side but behind the auditory meatus. A tape recorder was secured to the dorsal fin.

Everything became clear when the records were analyzed. Only the hydrophone in front of the blowhole recorded location pulses. No location pulses were detected in the other records, only barely audible whistles were recorded. Evidently, the air sacs and the skull bones reflected the acoustic waves completely. After being focused by the fat cushion, they propagate in the required direction and are not audible to one side. The auditory apparatus of the dolphin is reliably screened from the destructive effect of its own sound generator.

MUSTACHE, WHISKERS, BEARD

Most mammals, males as well as females, have a mustache, or to be more correct, vibrissae. They are long stiff hairs that serve as tactile organs. They grow on the head,

neck, and, in the case of squirrels and other animals living in the trees, also on the chest and belly. The vibrissae of cats are located on the upper jaw, about the nostrils, on the lower part of the chin and over the eyes, creating a peculiar nimbus about the face. The nimbus around the face of a small rodent, namely, a gerbille, is more than 10 cm in diameter though its body is only about 10 cm long. The hairs point slightly forward and the little creature, wandering in the darkness, can feel a wall that is 3 cm away from the tip of its nose.

Vibrissae, like all other hair, are set in hair follicles. The nerve fibres in the walls of the latter perceive the slightest movement of the hair. When its tip touches an object, it acts like a lever, pressing on the nerve endings. The vibrissae form a receptor with a large perceiving surface area and a high sensitivity.

The luxurious mustache of a cat enables them to analyze accurately the world around them, even the movements of a little mouse if it touches the mustache. Each hair transmits information to the brain only if it is bent in a certain direction. The vibrissae in different parts of the body are tuned to perceive different directions of movement. When analyzing the obtained information, the brain considers the character and direction of movements of the different parts of the animal's body that have vibrissae. This makes it possible to obtain exhaustive information, indicating whether the owner of the mustache is dealing with a stationary object or a live creature, and also to obtain data about its size and weight.

The vibrissae are undoubtedly necessary, especially if the vision is insufficient. Cats, hunting preferably during the night and in thickets, possess more developed vibrissae than representatives of the canine family, who prefer open areas and hunt during the light time of the day. Animals that burrow possess excellent vibrissae. Gerbilles spend a greater part of their lives in burrows. A mole has a whole set of

vibrissae and will not appear above the surface unless really necessary. Travelling along dark dungeons, they are preceded by their vibrissae which reconnoiter the surroundings.

Aquatic animals, for example, otters, beavers, seals, fur seals, and kalans also have vibrissae. When searching for food, they look under snags and stones, and catch their prey in thickets of aquatic plants, or grab it on the bottom. A turbid cloud is stirred up from the muddy bottom at a slightest movement and vision immediately becomes useless. The shift of the sensitive receptors to the mug and jaws, which are the working apparatuses of a predator, helps them when catching a prey. It is for this reason that Japanese designers have improved one of their robots and set the "eye" of their brain child on the manipulator. This made it possible to develop a program for the complicated operation of selecting a component marked with a cross among many absolutely similar components, and picking it up with the manipulator.

Evidently, vibrissae are used also as organs of distant reception. A tiny bird taking wing from under the nose of a jungle cat that has worked its way in the darkness through the thick jungle will cause motion of the air that is perceived by the predator because of the sensitivity of its vibrissae. Distant reception functions more reliably in water which is a denser medium. A seal chasing a fish must perceive at close distances the movements of the tail of the escaping prey.

It is quite possible that the vibrissae are used as organs of active location. The pressure waves, caused by a running cat or a lynx, and even more so by a sea lion swimming underwater will be reflected from a solid obstacle and return without missing the animal. Animals that burrow must use active location. A mole digs its intricate tunnels quite narrow on purpose. When the animal travels along the tunnel, its body tightly fits the walls of the burrow. Moving like a piston, the mole pushes forward an air column. The

pressure waves are much stronger in the burrow than in the open air. The mole will certainly not discard the information transmitted by the reflected waves.

Giant whales have also preserved mustaches and whiskers. They grow in three groups: on the edges of the upper jaw and on the surface of the head. Bearing in mind the size of the whales, they have a little number of hairs: the Greenland right whale has 250, and the finback whale has only 50-100. The vibrissae are thin, being only 0.2-0.4 mm thick, while their length hardly reaches 1 cm.

Toothed whales are not keen on mustaches. The narwhal and the white whale have none. Sperm and pilot whales have mustaches but only before birth. Most dolphins have their mustaches during their early childhood. The mustache starts fading at 1-2 months, and by 3-5 months they look cleanly shaved. It is true that tiny pits remain on the dolpin's face from the hairs with a small "stump" of the former hair at the bottom surrounded by nerve fibres. Nobody knows today about the function of the "stump". River dolphins are the only ones that keep their mustache throughout life. Evidently, the necessity of catching their prey on the bottom and digging in the silt makes the river dolphins abstain from this fashion. Their vibrissae are bigger than those of the whales, being up to 1 mm in cross section and 1.5-2.0 cm in length. They are slightly flattened and, unlike the vibrissae of land animals, do not narrow very much up to the very tip. Each hair is bent in the middle, and its tip is directed toward the skin.

What do big whales need a mustache for? Most of them feed on small squids, fish and very tiny crustaceans. The whale's eyes are so arranged that it does not see its prey when the latter is very close. This is a "blind spot" from where information is only transmitted to the brain by the tactile apparatus of the vibrissae. The whale knows that it is time to open its mouth when the animal's head enters a cluster of krill and the crustacea begin to touch its mus-

tache. The sensitivity of the vibrissae is phenomenal. Each hair sac is connected to 400-10,000 nerve fibres, this is far more than the number of telephone lines connecting Moscow and Leningrad. Involuntarily one will sense the touch of the tiniest crustacea, the tiniest bug.

The vibrissae are especially sensitive in some pinnipeds. A Californian female fur seal grabs the mustache of a rough admirer when she wants to get rid of him. She does the same with her mate when she is suckling her offspring if he turns too annoying or dangerous for the baby. R. Berton, a British zoologist, relates that professional hunters take advantage of this "weakness' of walruses and hit their mustaches with bamboo sticks if the animals turn aggressive when people are visiting their breeding grounds. When their vibrissae were touched, the animals immediately calmed and everything was resolved without bloodshed.

The sense of smell is the most important organ for land mammals. It assists in orienting in the surrounding situation, when finding food, avoiding enemies, or exchanging information with their relatives. Common sense made scientists believe until only recently that the sense of smell could only be used in air medium. It was thought that smells could not propagate in water. Unfortunately common sense does not always promote the development of science. The very first experiments illustrated that fishes had a developed sense of smell and used it actively.

Whales have no sense of smell. Their breathing passages lack the olfactory epithelium and the olfactory nerves, while the olfactory lobes of the brain are reduced. However, observations indicate that dolphins use chemical signalling quite widely. Whalers have found that white whales begin panicing if they enter a region in which other whales had recently been killed. Evidently, they detect traces of the blood of the killed animals or special chemical substances for signalling danger. Zoologists know of numerous examples confirming the availability of chemical signalling.

V. Belkovich relates that a school of white whales were once swimming along their usual route near the Kanin Point and were frightened by a shot. They turned sharply to the open sea. The next school that reached this spot repeated the turn and swam for the open sea. Evidently, the frightened animals had excreted a substance into the sea as a signal of alarm. Special chemical signals of alarm are known in many animals.

The active chemical signalling by dolphins has yet to be proved. The Belkovich's observations have a simpler explanation. Every school of cetaceans leave chemical traces in the ocean. These consist of protein lubricant of the eyes, discharge from the anal glands of the males, urine (the animals continuously discharge this in small portions), and other excrements. Following the tracks of their comrades, dolphins were sufficiently clever to turn when they were convinced that those preceding them had done so suddenly.

Zoologists consider that baleen whales can determine quite accurately the salinity of the sea water. A salinity of 3.35-3.39 % is best for the zooplankton that the giant whales feed on, the plankton forming large clusters in such waters. Whales in search of food will not stay long in areas where salinity is not optimum and will leave fruitless zones by the shortest route, evidently, sensing the gradual change in the concentration of salt.

The gustatory analyzer of the dolphins deals with chemical reception. Small oblong pits have been found on the base of the tongue of cetaceans. Scientists consider that most fine gustatory analysis is performed in these pits. It is enough for the dolphin to open its mouth and gargle to obtain chemical information. The animals do this quite frequently.

Baleen whales do not have pits on their tongues but they do have some kind of paired depressions at the end of the upper jaw. These are possibly intended for chemical analysis. Could the gustatory receptors be outside the oral cavi-

ty? Why not! Fishes have the greatest number of chemical receptors, i.e. gustatory tubercles. Their entire oral cavities from gullets to their lips are studded with them. Many fishes have them on their vibrissae, gills, head, fins and even distributed over the body surface. The gustatory tubercles inform them of all the substances dissolved in the water. Fishes can taste even by those parts of the skin that lack gustatory papillae, they simply use the cutaneous nerves. Fishes use their chemical analyzer skillfully. A hake and a gurnard, which dig in the bottom silt with their fins covered with gustatory tubercles, determine by taste whether there is anything edible there.

The external arrangement of the chemical analyzer is quite common. The front legs are the gustatory organs of butterflies and house flies. This is very convenient for them. The fly lands on an object that it is interested in and immediately determines whether it is edible. The gustatory sensitivity of the legs is 5 times that of the mouthpart, and it increases hundreds of times if the fly is left hungry.

It is still a mystery whether cetaceans, including baleen whales, have external chemical receptors. But are whales inferior to fish? Echolocation is a reliable method of orienting in the surrounding medium but it is hard to manage with only it. Vision, chemical reception and whiskers help the whales feel comfortable in the ocean.

PARROTS ONLY TALK IN CAGES

Speech is the basis of thought and is the privilege of man. Zoologists and now ethologists have begun to use the term "animal language". This term is widely recognized today. More and more data are accumulated every year on information exchange between animals. All the signals used for communication, including the olfactory, tactile, vibrational visual, and light signals as well as auditory ones comprise the language of animals, thereby stressing that it is a

lower order language only remotely similar to human speech. Animal behaviour is based on the signs ("words") of this language and regulated by the latter. The existence of most species would be impossible without exchange of information. These signals comprise those of danger and assembly, calls to lunch and requests for supper, declarations of love, and no entrance signs at the borders of their territories, and lots of other things that animals consider necessary to inform their relatives about. The vocabularies of animals are far behind that even of two-three year old children. It is comparable with the vocabulary of Ella the Cannibal in the novel of Ilph and Petrov as she managed with just 32 words. Nevertheless, the exchange of signals makes it possible for the animals to "discuss" all the important events.

We know the animal language very poorly. Rooks use 12 signals during the mating season. Eighteen signals have been described which we know hamadryas baboons use to exchange views. The language of chickens, whose stupidity is known to everyone, has about three dozen "words". This is far from the limit for animals. G. Eister, a British veterinarian who has studied the behaviour of horses for 20 years, has stated that their vocal language contains more than 100 "words"! Horses can understand information from other horses even when transmitted via a poorly made tape recording.

The language of the animals is innate: they neither learn to speak it nor to understand it. They only learn "foreign" languages. It is always important to understand one's neighbours, at least information on major events, for example, danger or the discovery of stores of food. There are even some generally used "international" languages which are more popular with animals than Esperanto is in human society. The language of ravens and magpies is quite popular on land. Their signals of alarm are widely known. The language of cormorants is well-known to those who live near the sea. Seals dive immediately on hearing signals of alarm produced by birds.

The ability to understand foreign speech is a passive knowledge of the language. Animals are still less able to use actively a borrowed system of signals, i.e. to reproduce the "words" of a foreign language. These abilities have only been found in the evolved animals such as monkeys, elephants, dogs, horses, bears, pigs, and mocking-birds. Starlings, crows, daws, and parrots, who are loved by everyone, can even copy human speech, which once caused a commotion in the ranks of the Catholic church. Owing to the close attention paid by Vatican to these birds that were brought to Europe from overseas, the latter were called parrots, which in Italian means "papal rooster".

A talk with a parrot can be quite interesting. A parrot named Kolya from Congo was brought several years ago to Rostov-on-Don. It knows 170 sentences, the longest ones consisting of 12 words. When it is in a good mood, it sings "Captain, Captain, smile ...", and when unhappy, it cries "Oh, our parting, our parting ...". A talk with such a linguist can be quite intelligible. A gray African parrot named Vovochka was brought to Leningrad by sailors and used to shout hysterically "Drink! Drink!" when it found that his drinking bowl was dry, or it would announce categorically to its master "Vovochka wants salad!" if it wanted some greens. When it was asked "How is life?", it would reply philosophically "Like a fairy-tale!"

A parrot named Kuksy frequently presented its wisdom to its listeners. Once its master's son, who was in his first year at school, came home in tears because he had had a fight with his friends on the way home. Naturally, it was not easy for the bird to comprehend human sorrows. When his master came home from work and asked the standard question "Well, Kuksy, how is life?", the parrot mournfully bent its head and hiding its eyes replied "Again a bad mark!"

As you see, a parrot makes quite good company. No other animal, even monkey, is capable of speech. It is possible to

teach with some patience some birds of the Corvidae family to pronounce about two dozen words. Given a certain condescension this is quite enough for having an evening with a pleasant chat.

The fact that the language of animals is innate is itself convincing proof of its primitiveness, for genetic programs can only contain major information for versatile situations. However, the word "language" casts a spell and makes one look for someone with whom it would be possible to talk as an equal. Even if birds with their tiny primitive brain can imitate human speech, then can we not assume that creatures that are undoubtedly cleverer and more capable can also have the same ability? The discoveries which are sometimes made in this field fall into the hands of scientists and, even more so, reporters who are not very strict to their scientific information or are easily carried away usually turn into legends that have very little in common with reality.

G. Lilly, an American scientist, conducted some experiments two decades ago that have become widely known. He set out to teach a dolphin English. It is hard to judge how deeply he believed in the feasibility of his program. It is simpler to assume that the experiment was well financed. It is easy to understand what sort of sensation can be organized in the USA over dolphins if you see the American film "The Day of the Dolphin". In any case Lilly stated in public that the mankind would establish in ten-twenty years communication with other biological species. The scientist systematically conducted lessons in English with bottle-nosed dolphins and it seemed to him was quite successful. He informed the world in books and articles that the dolphins taught in his laboratory at Saint Thomas Island imitated human speech. Most sensational was the statement made by Lizzy, who pronounced it several hours before its death. At the end of the working day, as the tired researchers were hurrying to end the experiment, Lizzy interrupted their discussion and cried out "This is a trick". However, Lilly later

admitted that it was possibly, a poor reproduction of the phrase "It's six o'clock".

Lizzy's remark was recorded on tape, but we'll never learn what she had in mind. Lilly explained that it is difficult to recognize the words pronounced by the bottle-nosed dolphins owing to their dolphin "accent". It seems that imitating human speech the animals use all their acoustic abilities, including the high-frequency components. Lilly filtered out all the sounds above 5 kHz and amplified the lower ones in order to make the dolphin's expressions comprehensible to humans. In addition he reduced the speed of the sound reproduction 4-16 times. Even so Lilly said it was necessary to be accustomed to the dolphin's "accent" in order to recognize the English pronounced by the dolphin (or, to be more precise, certain imagination was required). Lilly acknowledges that even not all his co-workers, who were permanently communicating with the same animals and, evidently, learned well the dolphin's "accent", agreed that the dolphins were imitating human speech. You can judge for yourself how valid their conclusions about contacts with dolphins are.

Lilly persistently attempted to establish contact with dolphins. In one experiment his co-worker Margaret Hadd spent two and a half months with a young dolphin named Peter. They lived in the same pool and never parted for a minute. Peter preferred to stay in deeper part of the pool, while Margaret chose the shallow waters, which was quite understandable. She slept on a platform suspended from the ceiling. They became friends during the period they lived together. The first words, that Peter learned, were "ball" (a ball is the favourite toy of a dolphin) and "hallo" ("hallo" was used to indicate breaks in the games and lessons). Margaret surely understood well the intonations of her student, and yet she still had to recognize that the dolphin pronounced the words inaccurately even at the end of the experiment.

Let's leave the linguistic miracles on the conscience of Lilly, and not be distressed that meetings with speaking dolhpins are not anticipated in the next few decades. It is more important to clear up exactly which language dolphins do use when communicating with one another. It is most simple to assume that sounds are used for communication. Audio signalling is widespread in the animal world. It has certain advantages over visual and olfactory signalling as it permits animals to exchange signals over quite long distances and the pitch darkness of the night is no obstacle. The developed sound-reproducing apparatus and good hearing of dolphins leads us to assume that their system of communication is an audio one.

Observations of wild animals and specially set experiments have confirmed that they employ an audible language. D. Bastian, an American zoologist, set out to learn whether dolphins exchanged information systematically and how completely they informed one another about changes in the surrounding medium. The results of these interesting experiments have been published in hundreds of books, articles and stories. Essentially one of the dolphins instructs its companion about how to behave. It was impossible to decode the dolphin's language, but the experiments showed one to exist. Bastian's experiments are so well known that there would be no sense in retelling them if all the information available concerning his results and conclusions were presented correctly.

Bastian had a male and a female, which was a guarantee that the relations between the animals would be friendly and without competition. The pool where the animals were kept was partitioned into two halves so that the animals could see each other. The animals were trained to feed in their respective compartments. Wild dolphins while hunting are quite disciplined and they like a strict regime. Then two floats were fixed in each compartment and the training of the animals started. The dolphins were to depress the left-

hand float when a blinking light signal was given, and press the right-hand float when the light signal was continuous. A special lamp lighted up before each signal, indicating "On your marks!" The animals were rewarded only if both fulfilled the task correctly and the male was the first to depress the lever. Hence, the female was usually in no hurry to fulfil the command and watched the actions of her partner with interest, reacting quite emotionally to his success or failure.

When the animals had learned what to do, the pool was divided by an opaque partition which did not hinder the exchange of audio signals between the animals. They heard one another and knew what the other had done owing to echolocation. The start-up lamp alone was left in the compartment of the male, while the female's compartment had both signalling lamps. Now only the female could see the light signal, indicating which float had to be depressed, but both animals could see the start-up lamp.

The animals rarely made mistakes when they saw each other. However the appearance of the opaque partition did not change the results. It seemed that the female was informing her partner in detail about the light signals. She continued to "watch" the activities of the male and expressed quite emotionally her dissatisfaction or approval. This assumption seems to be true because the male started to make mistakes systematically when the tarpaulin partition was replaced by a rubber one and the animals could not hear each other.

What did the female's sounds mean? Were they a simple expression of emotion or did the signals contain information about the conditioned stimuli? A careful study of her audio signals during the experiment did not answer this question. The experimentors could not detect any definite signals the male could have followed. All the tapes containing the sounds emitted by the dolphins (almost 20 km of magnetic tape) had to be treated with special analyzers and processed

by computers. It turned out that the female emitted a short series of echolocation clicks when the blinking light went on. If the light was continuous, there were no echolocation clicks in the records. This was the source of information for the male.

It seemed that the problem of the dolphin's language had been solved, but Bastian thought differently. He decided to check whether the female was consciously informing the male about the experimental situation, or he was reacting to sounds that she emitted accidentally. He therefore decided to retrain the dolphins.

The animals were trained separately. Now they had to depress the left-hand float if the lamp burned continuously, and the right-hand one if the light was blinking. When the experimental animals were well trained to do as required, they were brought back to the experimental pool. The animals worked together very well and, although the male could not see the light of the signal lamps, he acted correctly in 9 cases out of 10. Kilometers of tape recordings were again analyzed. If the animals used their "dolphin" language, then the female had to generate a brief series of echolocation clicks in response to the blinking light in order to prompt the male that it was necessary to depress the right-hand float. The analysis indicated that the acoustic reactions of the female had changed. Now, in case of any light signal she responded by a quite long series of location pulses, but in case of blinking light the clicks were generated less frequently than for continuous light. The experiments confirmed that the male had been reacting to sounds generated by the female accidentally and not to special commands.

The next experiment finally convinced the experimentors that the acoustic reactions of the female were not intended for the male's ears at all. When the tarpaulin that prevented the male from seeing the light signals was removed, and there was no longer any need to prompt him, the female

continued to react to the lamps in the male's compartment by a series of brief or rarer clicks that depended on what the light signal was. She continued to behave in the same way even when the male was removed to another pool and the animals could neither see nor hear each other. Wasn't this proof that the audio signals of the female were not intended for anyone?

In order to end the discussion on the Bastian's experiments it remains for us to explain why the female acquired the habit of generating certain sounds during the experiment. It is a mere trifle to develop a conditioned reflex in a monkey to make it depress a pedal or a lever. Monkeys are always grabbing, pressing, or breaking off something under natural conditions and these actions frequently bring them some reward. It is quite different with dolphins. They usually avoid touching strange objects. And the experimental procedure of touching the float and getting a fish must have seemed fantastic to them. Nothing even remotely similar occurs in the everyday life of dolphins. It is no surprise therefore that conditioned reflexes like this were first induced in them with certain difficulty. However the generation of sounds is an ordinary matter for them. Sounds are generated in any situation, including the process of hunting, and it is absolutely necessary to do it to gain success. A mass of sounds are generated during the experiment. When the dolphin did for the first time what the experimentor wanted and was rewarded with a fish, the sounds that it generated (though nobody paid any attention to them) were also 'sealed' and became an indispensable part of the conditioned reflex. The conditioned acoustic reflex of the female in Bastian's experiments turned into the conditioned stimulus of the conditioned motor reflex of the male. Thus the experimentors had developed and secured a system of interrelated conditioned reflexes in the dolphins, which constituted the model of their communication system.

These forms of individually induced methods of information exchange may obviously also occur in the wild under favourable conditions for their appearance. They represent a considerable step forward compared with innate systems of communication. However, it is necessary to bear in mind that the vocal reactions of the female comprise no indications of the quality of the perceived visual stimulus. Bastian stressed that his experiments did not make it possible to consider these to be abilities of the dolphins. The sensation that dolphins have a highly developed language is on the conscience of reporters.

The existence of words in the human sense in the dolphin's language can be solved by a systematic analysis of the signals that the animals generate. The group behaviour of cetaceans is so complicated that the simple sounds they generate would seem to be insufficient for the exchange of information even about urgent needs. A way out of this difficult situation would be for them to use complex signals created by combining simple sounds, i.e. the way humans add sounds into phonemes, phonemes into words, words into phrases. If it is assumed that the principle of encoding information by creating a large number of combinations from simple signs is common for dolphins and humans, then the principles of decoding ought to be similar. An archaeologist finding inscriptions in an unknown language will begin by counting the number of different signs. Let's assume that the unknown writer used 26 letters (the number of letters in the Latin alphabet, which is used in English, German, French, Spanish and some other European languages). The number of combinations of 26 signs is 400 000 000 000 000 000 000 000 000. Humans use only some of these combinations. It will be expressed in percentage term by unity divided a one followed by 18 zeroes. If we find that the individual simple signals of the dolphins are combined into a relatively small number of combinations and the latter are used systematically, while the majority

of the possible combinations are not employed at all, then we may assume that these are the words or phrases of the dolphin's language.

It is extremely difficult to carry out this experiment. The research is restrained by the lack of instrumentation that can perform true analysis of the complex sounds, and by the exceptionally labour-consuming character of the research. Soviet scientists have attempted to analyze the signals of the animals under eight situations of communication with humans. It was possible to isolate 31 elements in the generated sounds (in other words, 31 "letters"). The composition of a complex signal comprised up to 24 elements. European languages do not have such long words. However, most dolphin's words consist of 2-5 elements. Scientists do not try yet to understand their meaning.

Two thousand whistles have been analyzed in another experiment. It turned out that they can be classified into 59 types. It is quite clear that not all the types have yet been determined. Complex whistles are encountered more frequently than simple ones. They are made up of simple whistles by successive or parallel combination. It is impossible today to understand the information contained therein. It was only possible to observe that certain types of whistles were used more frequently under certain conditions than others. The process of decoding the dolphin's language may be simplified if all the sounds that certainly do not transmit special information are eliminated. The analysis indicated that whistles lasting longer than a second are emotional reactions. They appear when the animals are very excited but do not reflect the reason that caused them, no matter whether it is positive or negative. Consequently, they contain no information about the mood of the dolphin. A frightened dolphin will produce the same whistles during a storm as it does during play-time.

A human is a poor interlocuter for a dolphin. When investigating their language, it is more reasonable not to ana-

lyze the sounds that are addressed to a human, but rather to analyze those generated by the dolphins when they communicate with one another. In one experiment Soviet scientists isolated two pools and connected them by an underwater telephone.

This made it possible for the dolphins to exchange information freely while the researchers tapped the telephone cable and recorded the dolphins' dialogues on tape.

The "conversation" between the animals sometimes faded away completely, while in other cases it became quite lively. Dolphins never kept quiet for long. Each animal "speaks" quite constant norm. They use single sounds quite rarely and more often complex sounds are used. A lonely dolphin is more taciturn than when it is on the telephone. The conversations between the animals resembled real dialogues. Long monologues were followed by brief remarks. The conversation sometimes became emotional. The interlocuters interrupted each other, one expressing its objections before the other had finished stating its ideas. Then the other too would lose patience and in turn interrupted the former. Sometimes they spoke simultaneously, at other times they performed a duet, producing the same sounds and synchronizing their beginning and end. Evidently, the character, the sequence of the sounds and the intervals between them had a certain meaning for the animals.

The researchers interferred in lively conversations by interrupting telephone line from time to time for two minutes. Some of the animals did not react to these intervals, evidently, they did not notice them. Others reacted only by the end of the interval and stopped conversing. A third group of animals detected the disturbance immediately and reacted quite emotionally.

A dolphin in an individual pool produces the same signal continuously. This was called an identifying signal. Scientists consider it to be a personal call sign. When American scientists observed the animals under these conditions, they

decided that the dolphin's language was quite primitive and that the animals could not transmit any special information about their environment. They believe that all the conversations are exhausted by a mutual exchange of identifying and emotional signals required for maintaining contact between the members of the school, and contain information about changes in their moods. Soviet scientists disagree with these views. Dolphins generate a variety of sounds. Their identifying signals only seem identical to our ear. An analysis has indicated that they have a common constant component that combines with systematically changing sounds. Evidently, these are the sounds that carry a sensible load.

The identifying signals of different dolphins are unlike each other, though sometimes the animals generate somebody else's call signs. What this may mean is still unclear. Maybe the animals, like parrots, mimic each other, and possibly the members of a school call a friend in this way, inviting it into a conversation.

Echolocation is an active method of analysing the surroundings. It creates prerequisites for the development of a special communication system that is inaccessible to other animals. Operating perfectly their own audio-signal generators and being inclined to imitate sound, though not to the extent Lilly believes possible, the animals may employ echo imitation to communicate news to their relatives. This assumption is quite probable and some observations confirm it. For example, it has been observed that porpoises employ signals for communication that resemble location pulses.

The use of echo copies for transmitting information can make a communication quite complete. A location pulse returning to the dolphin as a weak echo contains sufficiently complete information about the object that reflected it. Why shouldn't the dolphin repeat this echo-signal louder so that the entire school can hear it? If this method of transmitting information is used, it is undoubtedly combined with innate communication signals. Let's assume that a member

of the school has detected a net. The animal utters a whistle signal of alarm and simultaneously generates a copy of the location pulse echo that was reflected from the net. Thus, the members of the school are warned of danger and informed about its origin. A patrolling dolphin locating a school of mackerel, could send a signal inviting its friends to start a hunt and reproduce a copy of the echo that it received when probing the fish school. The school would be able to decide whether it was a promising situation when it received information from the patrol about the dimensions of the fish school, the size and species of the fish. The fact that dolphins can simultaneously generate whistles and location pulses is indisputable, having been noted by every researcher.

This method of transformitting information is quite economical. I had to make up long sentences of tell you about the objects that were used in the experiments with the dolphins. How else could I explain the reader that a ball had been lowered into the pond, that it was made of steel and had a diameter of 50 mm? The dolphin receives all this information from one location pulse that is reflected from the ball. Engineers should consider that possibly it was more advisable to employ this method in our technical communication lines. Evidently, cetaceans will be an object of intent investigation for a long time to come.

Rivals

COWS-DIVERS

Asian countries startle everyone by their exotic character. What will one not come across there! Several years ago one of the commodities exported from the Kalimantan Island included the tears of a sea cow. The "fishers" of Semarang "bottled" the tears and sold them for one and a half thousand rupees a bottle.

Despite the doubtful quality and unclear origin of this surprising liquid, it is in great demand in the countries surrounding the Indian Ocean. The department of the fishing industry has been flooded with so many requests for this commodity that the chief of the department had to print a special form stating that his offices did not trade and had no intention in trading the tears of sea cows or any other animals.

The sickly interest in the tears of sea cows is explained very easily. The inhabitants of the innumerable islands in the Indian Ocean believe that they are powerful love potions. They make the most uncomely man so attractive to the woman that her fate is solved.

The sea cow tears are as mythical as pigeon's milk. The point is that real sea cows, or to be more precise, Steller's sea cows (an animal discovered in 1741 by Bering's expedition to the Commander Islands and named in honour of the junior scientific assistant and the doctor of the expedition, George Steller) were exterminated more than two hundred years ago. They were slaughtered with really incredible speed, i.e. within 27 years. The last sea cow was killed on Bering Island and eaten by Popov and his detachment. It was the same Popov after whom an island in the Sea of Japan not far from Vladivostok is named.

Sea cow is the popular name of a peculiar aquatic mammals called the dugongs. These belong to the order Sirenia together with the manatee that inhabit the Atlantic Ocean. The existence of dugongs might have been the cause of the legends of sirens, nymphs, naiads and later of mermaids, who were beautiful women with a fish's tail instead of legs. Ancient Greeks believed in the existence of sirens and were terribly afraid of them. It was believed that these marine beauties lured trustful mariners to their destruction by their charming singing. Legends maintained that Odysseus was the first man to hear sirens and remain alive. Sailing past the island where the sirens lived he poured wax into the

ears of his sailors as advised by the sorceress Kirky and then ordered that he be tied to the mast. Being in despair of their weakness, the sirens turned into rocks. Mariners of the tropical seas still believe that if someone is able to resist the enchanting songs of the sirens, the singer is doomed to death. This is why they are so persistent, a victory over a sailor is not just a question of prestige!

Intelligent people in ancient Rome had no doubts that fish-tailed beauties really existed. Pliny the Elder wrote that the Nereids were not just fables. Oh, those Romans! Even fifteen hundred years later when Christopher Columbus was sailing in the Caribbean Sea in search of India and encountered manatees (the Atlantic relatives of the dugongs) he wrote in his diary for 9, January, 1493: "I saw three sirens sticking out of the water, but they were not at all as beautiful as it is said about them, though their muzzles really do resemble human faces".

Monks, adventures and scholars who visited America long after Columbus related of meetings with charming mermaids. Our ideas of female beauty had obviously undergone considerable changes since those times. One must possess great imagination to consider sea cows beautiful. The animal's snout is repulsive, and its eyes are small and inexpressive. It has two nostrils instead of a nose and these open only when breathing. Its lips are thick, ugly and split into two. The entire snout is covered with special tactile hair—vibrissae. A hairless skull instead of curly locks, no ears, and the skin is wrinkled. Manatees are dark-grey or black, and dugongs are red-grey to olive-green. The only resemblance with a woman is in their small bulging breast, each with one nipple. The breasts are neither on the belly, like a cow's udder, nor at the tail, like in a dolphin, but where they ought to be if they were not sea cows but really maids.

The largest sirenians known to humans were Steller's sea cows. They grew to 7-9 m in length and weighed up to 3-4 tonnes. Manatees are considerably smaller and old males

may be 4-5 m long and weigh about 700 kg. Dugongs are still smaller, being up to 3 m long and weighing up to 300 kg.

Instead of forelimbs sirenians have fins, which are longer and more flexible than in dolphins. Fishermen recount that the female dugongs hold their babies with their fins to the breast and stick out of the water to suckle them. The little one can suck milk and breathe at the same time. Possibly, this pose so characteristic of a nursing mother, was why the legends of the sea maids first arose, the remaining elaborations having been added by the fervid imagination of mariners. Manatees, at least those that live in seaquariums, do not imitate humans. They feed their babies underwater on their backs, and do not support the baby with their fins.

Sirenians have no hindlimbs. Their body ends with a horizontal tail fluke like whales have, instead of a vertical fluke like in fish. Manatees tail flukes are rounded while dugongs have a triangular bilobate flukes, resembling a dolphin's tail.

Sirenians inhabit coastal waters in the tropical regions of the oceans. Dugongs are found in the Eastern hemisphere: from the Red Sea and the African coast in the West to Australia in the South. Manatees live in the Atlantic Ocean near the African coast, along the southern coast of North America and the northern coast of South America, near the islands in the Caribbean Sea. Manatees are no match for dugongs; they are not such staunch "mariners", and readily travel up river mouths and even ranging up to Lake Chad in Africa inhabiting it permanently. A peculiar subspecies of clawless manatee is found in the Orinoco and Amazon rivers.

Sirenians are herbivorous animals. They keep to families or small herds in shallow coastal waters at a depth down to 20 m, where they find an abundance of sea grass and algae. Unlike their mythical relatives, the sea cows are quite phlegmatic. They doze in the daytime somewhere in the thicket

of the sea grass, floating motionlessly on the water's surface, but at twilight they begin to feed and if not satiated by dawn, they continue to feed after sunrise.

The adults are real gluttons. Manatees in captivity gulp down 30-50 kg of high caloric food every day. This includes carrots, cabbage, apples, bananas, tomatoes, melons, water melons, salad. Evidently, they need about 100 kg of the less nutritious sea grass. Sirenians feed from the bottom. Their massive heavy skeletons are why they have high specific weights, and this enables them to stay on the bottom and crawl from one spot to another. Grabbing a large tuft of grass by its fins, the animal pulls it closer to its mouth. The fleshy halves of the lips pick out separate stalks from this bouquet. The independently working lip halves move them over to the central groove, whence they are drawn into the mouth.

Sirenians reproduce very slowly. The females give birth to one and rarely two young. The gestation period is long being 5 months in the case of manatees, and 11 months with dugongs. The young grow slowly and suckle for about a year; a manatee will feed on its mother's milk for a year and a half.

The offspring are born underwater but immediately after birth the mother carries it to the surface. When the mother is convinced an hour or two later that the little one has become accustomed to the surroundings and is breathing normally, she begins to dive with it. Listening all the time very attentively, the mother takes care that its newborn does not forget to inhale air. If the father is present at the delivery, which happens quite frequently because the couple are movingly fond of each other and hardly ever part, he is clearly excited but does not assist in caring for the infant.

Despite the external resemblance with seals and a mode of life similar to that of whales, sirenians are not related to them. No matter how strange it might seem, their closest relatives are elephants. They have much in common irre-

spective of their extremely different appearance. First of all they both have mammary glands with one nipple on the breast. Sirenians have primary and secondary dentition as in the case of elephants. When the front molars wear away, the next ones develop in the jaws. Elephants and sirenians can live until they exhaust their store of molars. The three middle fingers on the fins of the manatees have flat toe-nails resembling those on the legs of elephants. Dugongs do not have these toe-nails but the males do possess small 20 cm tusks. Certainly, they are a far way from the African giants, but it is also true that sirenians have no intention of competing with them. They are not elephants, only their distant relatives.

Sirenians have very few enemies in the ocean. Caimen and alligators are only dangerous for young animals. Few large sharks, for example, tigar sharks, swim into coastal zones and stick their noses into the thicket of aquatic vegetation. However, even these blood-thirsty predators do not terrify grown up sirenians. The animals immediately discard their phlegm at the first sign of danger and disappear in the underwater thicket, using their powerful tail and fins.

Only a human presents a real threat for the sirenians. Hunters from coastal settlements have gone after dugongs for a long time. Armed with a heavy harpoon on a long rope, the hunters go alone in a light canoe in search of a sea cow.

Inhabiting the coastal waters, the sirenians keep very quiet and reserved. The animals remain motionless for hours on the surface of the water so that only a small part of their scaling backs, covered with a film of unicell algae, extends above the water. They lift their heads only once every 10-15 minutes to inhale fresh air. Their back can be easily mistaken for a cluster of dying algae. The inhalation and exhalation are very short, not more than 1-2 s, and entirely noiseless, dolphins doing the opposite.

Smell assists hunters detect the dugongs. Even Europeans, who lack such a refined sense of smell, can perceive the sharp smell of the animal's breath one or two hundreds metres away downwind. Experienced hunters find the oily trace of the animal's greasy lubricant on the water mirror surface of quiet lagoons. This leads the hunter to the daytime parking site of a dugong.

When a hunter finds a dugong, he slowly and carefully paddles his canoe up to it. By approaching it from the rear, the hunter is almost sure that his canoe will not be noticed, but the slightest noise—an unlucky turn of the paddle—and the tremendous animal disappears in the depth. The hunter is not discouraged because when the animal is moving, it has to surface more frequently to breathe, once every 1-2 minutes, and rarely once in 3-4 minutes. The hunter increases speed and tries to determine the underwater path of the animal and to reach the spot where it will surface to breathe in fresh air.

Approaching the animal, the hunter plunges his harpoon into the body of his prey. Then a contest of endurance and skill begins. The canoe speeds at 15-20 km/hr, being towed by the animal which is mad with pain and fear. The aim of the harpooner is to keep the canoe afloat and exhaust the wounded animal. The weakened prey is towed then to the shore.

Experienced hunters do not exhaust themselves with a long struggle. Having harpooned the dugong and letting it become a little tired, the hunter dives into the water and reaches the animal following the rope tied to the harpoon. Then the hunter clamps the nostrils of the dugong to prevent its breathing and, when the opportunity arrives, kills the animal by hitting it on the nose.

The other method of hunting was once practised when there were more dugongs. The hunters built a platform above the water's surface near a regular feeding ground of the animals. Armed with harpoons, they would hide on the plat-

form during moonlit nights and wait the herbivorous giants. Only a few animals could be caught using these methods of hunting which meant that the dugong population was not significantly decreased. However, the number of animals started to reduce rapidly with the appearance of Europeans with their firearms and nets. The situation deteriorated badly for the dugongs when it became rumoured that their meat, fat and especially their tears had medicinal properties. These tears, the fatty lubricant of the eyes, accumulate in the corners of the lid slit and run down its face when a wounded animal is dragged ashore. The hulla-baloo has died a little during the last decades, the price of the fat has fallen, but a hundred kilograms of good meat and the thick and easily dressed hide remain a desirable catch. The animals are sometimes hunted for sheer sport. Australia and some other oceanic states have recently banned the catching of dugongs using nets, which resulted in a certain increase in the number of animals as it seems near the Great Barrier Reef.

The fate of the manatees is less alarming. River-beds, navigable and irrigational canals in the tropical and subtropical regions of North America are being rapidly overgrown with aquatic vegetation. The water hyacinth is causing the greatest trouble because there is no method effective against it. Earlier the manatees restrained the growth of the hyacinths in the mouths of South American rivers. Sirenians have lived in the water reservoirs of the botanical gardens in Hayden since 1885 and it has been unnecessary there to clean away vegetation. The authorities in the USA hoped that these herbivorous enimals would ameliorate the situation. Experiments set in Florida illustrated that the animals really could clean the canals and rivers of the hyacinths. Unfortunately very few American sirenians are still alive, it is hard to catch them, they endure transportation very poorly and rarely reproduce in captivity. Evidently, the canals are too shallow to the taste of the manatees.

The attention the manatees have attracted was to their benefit. People started to protect the animals, first in the USA, then in Surinam, French Guiana, Venezuela, Guyana and other countries of Central America. There is even a reservation in Guyana where manatees live freely. Let us hope that the American sirenians have a chance to survive, as considered by R. Bertram, the British zoologist, who started the campaign to save them.

Today many seaquariums in America keep manatees as well as dolphins. These phlegmatic animals, whose appearance is not very attractive, prove to be very charming creatures. They get accustomed to people quite rapidly and easily. They take food from a human's hands on the second day. They easily change their way of life and turn from nocturnal animals into diurnal ones. They are never aggressive towards people. It turned out that they are not as silly as they might seem at first sight. They can be trained to perform various tricks in aquatic circuses. Living in captivity, the manatees transfer to humans the affection they give to the members of their own family. This is especially true of young manatees that have been artificially nursed by the workers of the seaquarium. They are ready to play all day round with their masters and part with them for the night with reluctance.

If we summarize all that is known today of sirenians, we wonder how thriftless humans are in real life. Sirenians simply beg to be domesticated. It is hard to say what else but the inertness of human thought has prevented sea cows from being domesticated several centuries ago, at least manatees, who are easily kept in captivity and sometimes even reproduce in seaquariums. Nobody can compete with them on underwater meadows and their excellent meat could solve the food problem on many oceanic islands. In addition. it would be possible, with certain persistence, to breed selectively a dairy species of manatees. They could supply fresh milk to the inhabitants of barren atolls where there is

no vegetation, thus making it impossible to keep the big ungulates.

Sirenians live in an environment similar to that of dolphins. Obviously their habitat creates to them more severe demands than to cetaceans. Sea cows live among rocks and thickets of sea grass and manatees readily visit river mouths and live in their turbid and opaque waters. This mode of life with its main activity at night requires a highly developed orientation system. Which sense organs take on this function?

Vision and smell cannot help in every situation. The large number of vibrissae on the snout and the stiff bristles on the body testify to highly developed tactility. But this is reception of close action. Then only echolocation is left.

Modern sirenians, unlike their legendary namesakes, are considered to be very taciturn creatures. However, emotionally excited dugongs grunt and whistle. Observations of manatees in captivity have shattered the notion that they remain silent. Like the other inhabitants of the "silent kingdom" sirenians are not silent. Creaking trills of 2.5-16 kHz with a duration of 0.15-0.5 s have been recorded by means of hydrophones. Scientists have not determined yet whether the sounds are an expression of emotional excitation of the animals, signals for communication with relatives, or location pulses. This question should soon be answered, but today it is known for sure that there is much in common between the hearing systems of manatees and dolphins. The auditory ossicles in the middle ear are massive, consisting of extremely dense bone substance and are rigidly interconnected, while the hearing regions in the brain are developed more than the others. Thus, sirenians do really possess sonars.

LIONS, ELEPHANTS, LEOPARDS

Quite a number of creatures inhabiting the spaciousness of the oceans are a problem from the point of view of echo-

location. Lions, leopards and elephants are currently "under examination". What I mean here are certainly sea elephants, sea lions and sea leopards. They all belong to a small order of pinnipeds, which includes about 30 species. They are big or very big animals ranging from 1.2 to 6 m in length and from 40 kg to 3.5 tonnes in weight. The females of some of the species are considerably smaller than the males. The older males of sea lions weigh more than a ton, while the females weigh 300-350 kg at most. The difference is still greater for the northern fur seals. The weight of adult males varies from 100 to 190 kg, while their graceful females rarely weigh more than 25-40 kg. Only the female sea leopards weigh more than the males.

Despite the essential differences in size, the pinnipeds are all similar in appearance, which is explained by their similar mode of life. They have elongated spindle-shaped bodies, narrowing in the front and the back. The relatively immobile thick neck is not separated either from the body or from the head. It is sufficiently mobile only in sea lions allowing them to perform quite complicated circus tricks. The relatively small head is always smaller in cross section than the neck. However, this little head with its small forehead contains such a large brain with many convolutions that a chimpanzee or an orangutang would envy.

The cold seas are the habitat of the pinnepeds, and only a few species are found in the tropics and subtropics, these including the monk seal, the southern fur seal, and the California sea lion. The Caspian seal only spends the summer in the subtropical zone in the South, and returns for the winter to the northern part of the Caspian Sea with its severe frosts and winds. Two species of seals have adapted to living in fresh water and both species live in the USSR. They are the Baikal and ringed seals. The latter is distributed in the northern seas as well as in the Lakes Ladoga and Saimaa.

Scientists believe that this group of animals has evolved from land predators. The ancestors of the pinnipeds were becoming accustomed to the sea and cautiously trying the water when the whales were already cruising in the oceans. Pinnipeds make up a young group of aquatic mammals. Unlike whales, dolphins and sea cows, they cannot be considered totally aquatic creatures. They are unable to survive without a solid base, whether it be land or ice. They leave their aquatic world to shed and for their honeymoon. The young are also born outside water. They cannot leave their hard bed. A bath in the sea will not benefit them and, besides, they have not been trained to swim.

On the other hand, if one looks at the pinnipeds more attentively, it is quite evident that they are typically aquatic creatures though they need land. This concerns first of all the food problem. They never feed ashore. All the food pinnipeds consume is in the water. Possibly, only a South American sea lion will catch a penguin ashore and then devour it. The pinnipeds feed on fish, crustaceans, and molluscs that cover the sea bottom. Some gourmands, for example, the Widdell seals, prefer cephalopod molluscs, namely, squid and cuttlefish. The name crabeater seal is simply an advertisement. This quite big animal feeds on small planktonic crustaceans, filtering the sea water through its tightly clenched teeth. Nature has equipped the crabeater seal with a special accessory to catch small crustaceans. Each tooth in the upper and lower jaws has several denticle projections and looks more like a comb than an accessory for chewing food.

It is a common phenomenon that aquatic giants feed on small fry. Although a leopard seal would prefer for dinner a well-fed penguin or a common seal that accidentally gapes in shallow waters, it feeds principally on krill. Catching small crustaceans does not much resemble hunting but the gathering of wild strawberries in thick grass. It requires a great deal of time and labour, but guarantees a nourishing

meal, unlike a pursuit after fast and cautious penguins.

The limbs of the pinnipeds are more adapted for swimming than for moving on land. A considerable proportion of their shortened skeletons is hidden within the body. Their unproportionately long hands and feet protrude outside. The fingers of the fore and hindlimbs are joined by webs. Pinnipeds are good swimmers. The main driving force for most species comes from the rear paddles, while the front ones are used for steering. However, this rule has many exceptions.

Walruses and seals frequently use all four limbs to swim, while sea elephants avoid using their front paddles even for steering. Finally, fur seals and sea lions usually use their forelimbs, while their hindlimbs perform the steering.

The animals are less confident on land. When seals go ashore, they only rest on their forelimbs and the rear paddles are stretched out behind them. Walruses and eared seals are the most land-loving pinnipeds and use all four limbs when moving on land. The best walker is the crabeating seal. It can move on ice so quickly that a human cannot overtake it.

The pinnipeds leave the water for shedding and mating. Some of them crawl out to the cliffs, others use pebble and sand beaches, while the southern sea elephant prefers at this time to take its ease on grass, or at least in peat fields with a soft cushion of moss. Some species of animals use floating ice for their summer quarters and nurseries, whereas some settle nearer to the hummocks, while others, for example, the ribbon and the Greenland seals, prefer large flat icefloes without hummocks or ice pieces. The animals stay in the water the rest of the year, principally near the coast and never go ashore even when there is an opportunity. The Baikal seal spends the winter beneath the ice. It makes small holes in the ice field that covers the lake for half a year. The holes are good enough for breathing but they are too small to crawl out. The Antarctic Weddell seal behaves

in a similar manner. Only a few species of pinnipeds like to relax on the ice. Other inhabitant of the southern hemisphere the crabeating seal which winters near the edge of the Antarctic ice skillfully jumps out of the water to land on high ice-floes. It is hardly possible to say they love the icy bed, they simply feel more comfortable on the ice than in the water where the eternally hungry killer whales may appear at any moment.

The skin of the pinnipeds, unlike that of their ancestors, who were predatory animals with a substantial layer of subcutaneous fat, is exceptionally thick, and unlike the other mammals living in the ocean, whales, for example, it is covered with hair, principally short stiff fur. Hair is not very convenient in water. It is not mere chance that has lead walruses to follow the experience of whales. The pitiful remains of hair on their bodies could not be called fur anymore. And on the contrary, northern fur seals still have excellent fur mantles with thick rough guard hair and soft down. 30,000-50,000 hairs of down cover 1 sq. cm of the skin! They have paid a high price for this fashion. The northern and southern fur seals have been mercilessly hunted in the past and have been on the verge of extinction. Only preservation measures saved the animals from complete disappearance. The number of seals has increased in the USSR to such a figure that it has now become possible to resume controlled hunting. The situation is much worse for the southern fur seals. Until 1888 a herd of about 3 million animals used to inhabit Juan Fernandez Island, which is 600 kilometres from the coast of Chile. Professional hunters exterminated all the animals. The few remaining fur seals evidently migrated elsewhere and only appeared again in 1964. The islands are now inhabited by about 750 animals.

Many seals are coated with very good warm fur, but even this fur cannot keep the seals warm in water. It is the fatty lining that keeps them warm and prevents the skin from warming up, which would be quite undesirable for the pin-

nipeds. Young sea elephants lose a considerabe amount of heat through their skin, and this gives them terrible trouble. When a young one is lying on the ice it melts such a deep font underneath it, that it is unable to crawl out and perishes if not assisted by its mother in good time. It is thought that about 15% of the young perish in their own cradles.

The animals, who are dressed in a fatty casing, are also threatened by a heat stroke due to overheating. As in whales, the paddles are cooling "windows". This is not enough for a sea elephant and its enormous body has six more cooling zones, three on each side. The rest of its body transfers very little heat because the skin is never warmer than 18 °C. However, the skin temperature rises to 29-34 °C in the spots intended for cooling. These spots are the first parts of the skin of a sea elephant to dry after it has been heated up after a fast swim and has crawled ashore to rest. When the skin temperature drops sufficiently, the elephant closes its "emergency windows" and the warm skin immediately cools down to 18-21 °C.

The fat which protects the animal against cooling is also valued by humans. Walruses, eared seals, sea elephants and other species of seals have been hunted for this fat. The stock of many species has decreased recently. Professional hunting of walruses has been banned everywhere in order to recover their numbers, and only the local population is allowed to hunt a strictly limited number of animals for their own needs.

The situation with sea elephants is not much better. The number of northern sea elephants on the Guadeloupe Island was scarcely more than one hundred by 1900. It required about 50 years of an absolute ban on hunting for the herd to increase to 15,000. Sea elephants were completely exterminated from the more southern regions of the Californian and Mexican coast. A small colony of these animals was only found in 1938 on the San Miguel Island. The herd increased rapidly owing to good protection and today it num-

bers from 35,000 to 40,000 animals. The population of the southern sea elephants is recovering at a slower rate.

The monk seal was also nearly exterminated as its meat is edible and rather tasty. All sailors from Columbus onwards have hunted these animals along the American coast. As a result the last monk seal was found in the Caribbean Sea in 1952. The Mediterranean monk seal has not been hunted for a long time. However, very few animals of this species have preserved in some regions of the Black and Mediterranean Seas, namely, in the mouth of the Danube, near the coasts of Bulgaria and Turkey and in the reservation on the Hvar Island in Yugoslavia. A colony of monk seals numbering 4-5 animals has been found recently at the western coast of Sicily.

Like every animal that breathes with its lungs, the pinnipeds are only guests in the Kingdom of Neptune. They visit it frequently but for a short time. Most species can only stay underwater for a few minutes, while the walruses and seals that live among ice fields can dive for 15-16 minutes. The pinnipeds possess the same accessories as the dolphins to enable them stay underwater. Their lungs are of a considerably greater volume than those of land predators of the same size. They have considerably more blood and consequently more haemoglobin, which carries oxygen. Their muscles contain even more oxygen, where it is bound by monoglobin. This store of oxygen in the muscles is enough for muscles to work for the whole time the animal is submerged. The heart is also adapted for work when the animal is underwater. The heart of the common and gray seals works extremely quickly when the animal surfaces, contracting 180 times a minute. This ensures rapid recovery of the oxygen store in the muscles. The store of oxygen is preserved if the animal has the opportunity to breathe fresh air. The heart beat reduces six times when the animal dives. The working muscles immediately become self-subsistent, and all the oxygen transported by the erythrocytes is con-

sumed by organs which lack their own store. The good supply of oxygen enables the northern fur seals to dive to 100 m, while the Weddell seals can even go down to 600 m!

The respiratory system of the pinnipeds supports the life underwater, but it is not as developed as that of whales. A major difference is in the way they inhale air. The nostrils are in the same place as in land animals, and this creates certain problems when the animals want to sleep. Owing to the subcutaneous fat the body of a pinniped weighs almost the same as that of the displaced water. Hence, it is not difficult to keep afloat, but the head is heavier than the water and it is necessary to lift it each time above the surface to breathe. A sleeping herd of walruses resembles a stream of boulders in a sudden shallow. This is because the dark-brown backs of the animals extending above the water. One of the animals will dive occasionally and then a head with a mustache and tusks appears above the water surface. The animal noisily inhales air with its eyes shut tightly, and then it dives and its back extends again above the surface. Their sleep is thus quite restless. Sometimes the walruses use a ring-buoy to sleep undisturbed. This is a neck air sac. The walruses fill it with air and sleep in a vertical position, extending their head and shoulders above the water. They don't have to change their pose in this case in order to breathe.

Pinnipeds have many other accessories for living in the high seas, for example, teeth. These are quite primitive compared with those of predators, hence they can be used for any purpose: catching a live prey, gnawing through a hole in the ice, or filtering out prey from water. Walruses use their tusks to stir up the sea bottom in search of molluscs, or use them like Alpine sticks to crawl out on the ice, but never for chewing food.

The fore paddles are not only used for swimming, some pinnipeds use them like hands despite their shape. A sea lion, catching a big fish, first kills it and then holding it in

its paddles close to its chest, surfaces and eats it slowly with pleasure. Walruses dive to the bottom and stir up the silt with their 60-80 cm long tusks, turning out the molluscs. Then they gather a heap of crustaceans together with the sand and silt using their paddles. They rise to the surface rubbing their paddles en route and rough surface of their "hands" helps clean the molluscs of dirt and crush their shells. Everything gradually falls from their clumsy paws, the shells directly to the bottom, while the lighter bodies of their owners go down much slower. The walrus collects and swallows its food before it reaches the bottom and then surfaces to breathe.

Perfect adaptation to the water enables the pinnipeds to go on long cruises annually. Fur seals appear in spring at the Commander and Kuril Islands. They have breeding grounds on Fur Seal and Pribilov Islands, and in winter they swim to the warmer waters near the Honshu Island. The distance the animals swim south only depends on their size. The young stay in water whose temperature is 15 °C and sometimes swim to warmer places. Females prefer cooler water, ranging from 6 to 12 °C while hardened males stay further north, and occasionally they are even found at the edge of the ice.

The main cause for the long cruises is to return to the grounds that were chosen long before for breeding. Many pinnipeds prefer to live in large groups and form large communities during the breeding period. They sometimes swim hundreds and thousands of kilometers in search of sites for the maternity homes. Most of the pinnipeds have been severely hunted by humans over the last few centuries. It is not surprising therefore that the animals seek hidden sites for breeding, most often uninhabited islands. At the very least they are beaches that are difficult to reach and rarely visited by humans. Eared seals will not use breeding grounds on rocks or beaches that can be approached from the land side. If there are fur seals on the grounds, then eared seals

may appear as they trust the cautiousness and experience of these beach masters.

The selection of a suitable site requires a good deal of time as the animals are very cautious. When a large herd of walruses approaches a beach, it will not go ashore immediately. The animals sniff the air for a long time, moo and grunt, exchanging information. Finally, having overcome their hesitation, they rush ashore. The animals are very tired after their long cruise and, having come ashore, immediately fall asleep with their head turned toward the water. They lie tightly pressed to each other. If the beach is small, the newly arriving walruses unceremoniously climb on backs of their comrades. Fierce fights never arise due to cramped conditions. Sometimes an especially offended animal will hit its neighbour with its tusks, or smack him with a paddle, but more often the smack will not hit its target.

Walruses have separate areas: the older males staying ashore, while the females and their young preferring ice floes. Sometimes there are so many on the ice floe that it tips over or sinks completely.

Fur seals are polygamous animals and gather harems at the breeding grounds. The older males are the first to return from their wanderings in the high seas. They occupy sites on the beach and wait for the arrival of the females. Fierce battles start when the females come as each mail strives to obtain more wives. Some harems can number a hundred or more females.

The females give birth to a single young a few days after returning to the breeding grounds. The baby is born with beautiful black fur. All pinnipeds are born with a thick and fluffy fur-coat. It is rather thin in the case of young walruses. The coat is obviously made of reject material and the hair soon begins to fall out. It is true that the young of other species also don't parade for long in their

apparel and shedding begins after 3-4 weeks. Only fur seals wear their coats for 2.5 months.

At first the young are quite helpless, being unable even to swim, but they grow very quickly. The milk of the pinnipeds contains up to 50% fat and an ample amount of protein. Female seals suckle for about a month. Little fur seals feed on milk until late autumn. At the beginning the young remain constantly near their mothers, but they soon begin to crawl away because it is dangerous for them to stay near the harem. They might be trampled to death in the whirl of bodies that occurs during the fights that go on continuously between the older males. Hence, kindergartens appear somewhere near the harems and these are visited regularly by the mothers. The female unerringly recognizes her baby, evidently by its smell, and feeds only it. At one and a half month little fur seals have learnt to swim and spend more time in the shallow waters of small bays protected against the waves. It is very difficult for them to maintain contact with their mothers at this time. The females begin to depart regularly into the sea for 6-8 days. When they return they must find their offspring otherwise it will perish of hunger. A strange mother will never feed it.

The mother meets its offspring in accordance with a special ritual and always at the same spot on the grounds. Having digested the milk it took from its mother 5-7 days before, a baby will crawl to the site where it was born and cries mournfully for its mother. The female goes there immediately it returns from the sea. The mother cries out loudly from time to time to summon her child. All the hungry babies crawling around immediately respond to her cry, except for those who have just been fed; they are so satiated that they have no strength to crawl and so keep quiet. This facilitates the search of the mother for her baby.

The female remembers the voice of her child, hence the responding cries of the other little fur seals are to no avail.

Only the voices of some of the babies will seem familiar to her. She sniffs them but then rejects a strange child. Finally, having found her offspring by its voice, she sniffs it thoroughly and convinced there is no confusion, begins to feed it, keeping off all the other hungry babies. The babies either do not remember their mother, or would feed wherever possible. As they say, hunger is not a relative.

Young seals are brought up in solitude. The offspring of the Caspian seal stays the whole day on the path to the water, while the mother stays underwater most of the time, crawling out only to feed her baby. This is also true of Greenland female seals. They only stay with their offspring during its first 7-10 days.

The ringed seal prepares a lair for its future offspring. When the sea begins to freeze, it hits the ice from beneath and makes holes in the ice-hummocks. At first the holes in the ice are small and can only be used for breathing, but the female gradually widens it with its teeth and the claws on her front paddles to the size of a passage. She shovels the lower layer of the snow into the hole, making a large cavity. The female selects one of several lairs where the thickness of the snow arch exceeds 50 cm and expands until it is 8 m long, 1 m wide and 60 cm high. The baby is born in this lair. Later the young one helps to build its home, digging out side passages up to 1.5 m in length. No matter how big the lair, the exit always directs into the water. The vapour of breathing condenses on the ceiling of the lair, forming an ice crust up to 2 cm thick. The ice castle is quite strong and an Arctic fox will spend quite some time to destroy the arch.

An indispensable part of the seal's home is the bath. This begins at the hole and sometimes extends along the entire lair, and is 10-25 cm deep. It always contains water and wet snow. If a predator penetrates the lair, the baby tries to hide in the bath.

The most considerate mothers are she-walruses. They nurse their babies, if a one-and-half ton animal may be called so, for at least a year and feed them with milk. The little walrus is unable to feed itself. The famous tusks cut out at the age of one year, and until this time they are unable to plough up the sea bottom.

Large communities of pinnipeds have strong herd instincts. A frightened herd of walruses is an impressive sight. In an attempt to escape the pursuers the animals dive down deep but even there they gather into a tight mass; they feel calmer next to each other. Pinnipeds have a developed sense of mutual assistance. At a moment of danger a mother walrus never leaves her offspring. If they are ashore, she takes even a wounded or dead baby into the water, holding it to her body with her paddles. As a rule, the young are caught for zoos that keep walruses. It is not a very pleasant operation. The infuriated mother attacks the boat taking away her baby, and sometimes manages to overturn it.

Our relations with seals could have been quite different if not for the constant pursuit. Even species, that are hunted less today are not very cautious toward people. Sea elephants and Weddell seals can be approached quite closely. The ribbon seal is the most trustful of northern seals. It is not difficult to approach it within gunshot distance. Eared seals have become considerably more trusting once their hunting was banned a long time ago. One group of animals has established a breeding ground near the Sakhalin port of Nevelsk. The animals settle near multistorey appartment blocks. It is true that the inhabitants of the city do not disturb their pinniped neighbours and contribute to creating comfort for the animals during the most nervous period of their life. Seals range into the Southern Dvina River annually in spring and reach the beaches near Arkhangelsk. If the seals are not frightened, it is possible to become friends with those that spend the winter near the ice holes. It is sometimes possible to become friendly even with the

cautious Baikal seal. Scientists have been thinking for a long time of establishing relations with the most valuable pinnipeds. The summer life of the fur seals has been supervised by humans during recent years and other species of seals are now under consideration. Experiments have been carried in the White Sea on setting up seal farms. Walruses are quite promising in this respect. The peaceful giants feed on molluscs and their herds could pasture in shallow waters, being shepherded from one underwater "field" to another. The advisablity of recovering former population of walruses and organizing professional hunting, as is the case with seals, is beyond any doubt.

Echolocation would certainly not be an irrelevance for animals that spend the greater part of their lives in the water and frequently hunt beneath the ice. Zoologists consider that the vision is poorly developed in the pinnipeds, though hunters who catch the Ladoga, Baikal, eared and common seals know how difficult it is to approach the animal sufficiently close. Their sense of smell is very good in most species, though there are some exceptions. It is supposed to be weak in sea lions. However, the animals could hardly use their sense of smell in water because their nostrils automatically close when they dive and the olfactory cavity is isolated from the environment. The vibrissae are significant receptors and are found in every species of pinnipeds. The vibrissae assist in the search for food, but they are the receptors at close distance.

Simple observations under natural conditions have confirmed that the pinnipeds use some sort of additional reception in water other than vision. Hunters have repeatedly caught animals that lacked vision completely due to eye disease. Observations of blind sea lions in captivity illustrated that the behaviour of the animals was no different from that of those capable of seeing. Presumably, they use echolocation.

Echolocation requires an excellent sense of hearing. Most of pinnipeds lack external helices. Only eared seals have some poor rudiments of the latter. However, these rudimentary ears do not participate in the function of hearing. The external auditory meatuses are surrounded by a special circular muscle. When the animal dives, it closes the external meatus, protecting the tympanic membrane against increased pressure. This procedure does not affect its hearing. The animals hear well both when they are underwater and ashore.

However, echolocation requires the generation of location pulses. Nature has furnished the pinnipeds with their share of vocal abilities and herds of the animals are noisy. The voices of individual animals at the breeding grounds merge into a common roar, which is audible from afar. It is impossible to talk near a beach full of fur seals as they cry too loudly. Eared seals and sea elephants have quite loud voices and their roaring is quite impressive. The chorus of gray seals on the Farne Island resembles the mooing of a herd of cows. As a matter of fact, the voices of mothers who summon their offspring in November are quite pleasant, having clearly human intonations. When the animals jump out of the water to flee from the killer whales, their signals of danger are truly alarming. Ross seals emit quite tuneful sounds. A seal's cry consists of a series of repeated similar short sounds. The Californian sea lion and the southern fur seal have regular intervals between the series of signals. Intermittent sounds are produced for communication as it is easier to notice them. Sounds that are perceived by the human ear as simple ones are often intermittent in character. The threatening roar of a walrus is in reality three separate sounds close to one another. The animals produce all these sounds when they crawl out of the water, but they cannot be used for echolocation.

Until recently nobody had studied echolocation in pinnipeds because it had never been observed that they produced

any sounds in the water. Location pulses had not been recorded in experiments. Fifteen years ago T. Polter, an American biologist, was lucky. He found that sea lions searching fish generated series of short pulses, up to 30 groups per second, the duration of each pulse being 3-5 ms. The frequency of the sounds fluctuated within 3 to 13 kHz. Southern fur seals from the Juan Fernandez Islands generate series of long pulses with a duration up to 0.1 s and a frequency up to 3 per second. These are low-frequency sounds of about 150 Hz. The Weddell seal sends its acoustic pulses forwards and upwards at a frequency of 30 kHz. The ringed seal, which is quite a promising animal from the point of view of echolocation, is capable of twittering, roaring, barking and yelping in the water. However, zoologists consider that all these sounds are used exclusively for communication.

The voices of seals have been studied quite extensively at New York Zoo, which keeps many species of pinnipeds. All the animals they examined generated clicks in the water.

The acoustic pulses of the Greenland seal consist of low-frequency sounds of 2 kHz, ringed seals and sea lions use 4 kHz sounds, crested seals use from 100 Hz to 16 kHz sounds, common seals use 12 kHz, and gray seals use from 6 to 30 kHz sounds. Many animals generated their pulses in pairs. The pinnipeds generate clicks more slowly than dolphins do. The crested seal is the champion in this respect: it generates 20 pulses per second. The location pulses are very weak and some researchers doubt whether these sounds are used for echolocation. They consider that such weak sounds could produce only a negligible echo that would be useful only over very short distances. Nevertheless, the animals use them. The clicks were generated in the daytime only when the animals were searching for food, while the rest of the time the seals swam quite silently.

The echolocation abilities of sea lions, who have been the favourites in circuses and zoos for a long time, have been studied best. Researchers have favoured them with respect to the other pinnipeds as they have favoured bottle-nosed dolphins with respect to their family. T. Polter was convinced that sea lions used echolocation actively. During the night the researchers threw similar pieces of fish and horse-flesh into a pool with sea lions. Most pinnipeds abstain from meat. Sea lions found fish rapidly if they were no further than 3 m away, while they never touched the horse-flesh. They never swam closer than 0.5 m to the flesh. Most likely the animals could not use their sense of smell as their nostrils are always closed underwater. The researchers became convinced that sea lions could be taught to recognize different species of fish in the darkness. The animals pursued fish they liked and caught them easily, while less tasty fish were simply ignored. However, observations of the choice of fish are not telling arguments in favour of echolocation. Undoubtedly, live fish produced certain sounds, or differed in "gait", creating particular vibration-acoustic patterns when they moved thus allowing the animals to recognise them unerringly.

Sea lions, and many seals, produce double clicks when searching for fish. The animals generate them when approaching the object that evokes their interest. The first click in the pair is always the higher in frequency and shorter, being 8 times shorter than the second one. The intervals between the clicks in the pair are very short; they are 40-400 times shorter than the intervals between individual pairs. The advantages the animals receive from the double clicks are still unknown. It seems to the researchers that they assist the pinnipeds determine the distance to the object they are pursuing more correctly.

Scientists are not unanimous yet as to whether the animals use sonar under natural conditions. Direct investigation of the reaction of a sea lion's brain to sound has illus-

trated that their auditory centres are not as developed as dolphins', being adapted only to analyze short sounds, which are usually employed for location. The throughput of the auditory centres is relatively small and considerably less than that of dolphins. Observing that the pinniped's sonar is significantly more primitive than a whale's, scientists believe that the cause lies in the lack of training. The animals which always live in clear water, never use echolocation, but they can be urged to do so. This assumption has been partially confirmed by experiments with eared seals. Two males were kept in absolute darkness in a special soundproof pool and were only fed with live fish that they had to catch themselves. One of them soon learned to generate location pulses and used them when pursuing its prey. The other animal did not learn how to echolocate even after two months of the experiment. When catching fish, it used only passive location, listening to the sounds emitted by the fish.

The sonar of the pinnipeds is, evidently, well protected against interference. Any sound ought to reverberate from the walls, bottom and water surface in metal and reinforced concrete pools. However, the reverberation of the acoustic pulses themselves and the noise created by the neighbours in the pool do not seem to worsen the quality of its operation. When the interference was strong, the operation of the sonar was readjusted and its function did not worsen. Once, when experimenting with sea lions, the loud noise of a pump operating in a neighbouring room was quite disturbing. At first the animals were discouraged. They started to change the duration and frequency of their location pulses, but when this didn't work they became adapted to the rhythm of the pump, timing the generation of their location pulses to the tiny intervals between the sounds produced by the pump. The acoustic problem was solved, and the experiment continued as if nothing was happening.

Bioacoustic research requires sensitive instrumentation. The location pulses of the pinnipeds have not been recorded

for a long time, not because their frequency was too low to be perceived by a human ear but because they were too quiet. The use of these location pulses is quite limited. They can only be applied for locating nearby objects. So it is natural to ask why has nature developed such a low-power sonar. It is quite possible that the animals can produce louder sounds, but avoid doing so in captivity. Sounds of high intensity would evoke such loud reverberations that it would be impossible to use sonar. Maybe weak location pulses are used to overcome the acoustic interference arising in artificial basins with flat stone walls. It is quite possible that their sonar is much more powerful in the wild. Scientists know today very little about the sonar of the pinnipeds under natural conditions.

RECRUITS

The evolution of living organisms is much faster than it is universally acknowledged. We simply do not notice it. While whales, dolphins, sea cows, and seals turned into typically aquatic animals so long ago that paleontologists are unable to trace their path to the ocean, the sea otter changed into a marine animal just before our eyes.

The sea otters, or kalans as they were called by mariners in olden times, inhabit the coastal regions of wild rocky islands, rocks and reefs. This animal is related neither to beavers, nor to rodents. Scientists had to work quite hard before they determined that sea otters were not related to seals but were second cousins to martens and sables, and cousins to sea beavers. They are found on the Kuril, Commander, and Aleutian Islands, in the South of Kamchatka, in Alaska, on the Medny Island, on the Californian coast, swim to the Sakhalin.

A sea otter is a quite large animal, growing to a length of almost 1.5 m. It has a massive long body, short neck and a small head with a mustache and small ears hidden in the

fur. The hind limbs are set wide apart and have been transformed, practically, into paddles with a short tail between them. The front feet are very short with webbed toes and a palm free of fur. The very thick and warm fur of the sea otter is brown-black with some grey hair. The fur is made up of thin wavy down from 1 to 3 cm long and the guard hairs. These are very flat in the middle and impart elasticity to the fur. The fur of the sea otter is highly valued but the coat is made in the wrong way. It seems that it belongs to a stranger, being a little oversized. Folds form on its belly when the animal is on its back. The warm fur-coat has given the sea otter poor service. The sea otter was known as far back as the XVII century from Russian explorers. The first scientific description of the animal was given by the participants of Bering's second expedition, namely, by S. Krasheninnikov and G. Steller. This information only served to encourage hunting and then to the virtual extermination of the sea otters. No trace could be found of the numerous herds by the end of the last century. Several hundred animals only remained alive along inaccessible regions of the northern coast of the Pacific Ocean.

Happily, measures have been adopted in good time and the Washington Convention banning the hunting of the animals was adopted in 1911. World War I and then the occupation of the Far East by the Japanese prevented the organization of animal protection in Soviet waters. However, the Soviet government adopted effective measures in 1924 that ensured positive results. The sea otters are slowly gaining their former numbers, and are returning to the areas where they were once found in abundance.

The favourite homes of sea otters are on capes ranging into the sea, small islands, rocks and stones extending from the water. They are usually around shallow waters. Thickets of seaweed flourish in these waters in spring, safeguarding the coastal line against the oceanic waves. Sea otters frequently stay in the water for several days in fine weather

during the summer. During the dayime they feed, play in the water, go for short swings, and at night they sleep on their backs in seaweed thickets. The animals try to entangle themselves in the stalks of the seaweeds and sleep quietly as if "tethered". Thus, they are not afraid of being carried away by the wind to the high seas. In winter the animals go ashore for the night and search for a hole or niche in the rocks that will protect them from the wind. They hide there during storms and sleep until the sea calms down.

Sea otters are gregarious animals and usually stay in communities. They are very friendly and never argue. A large herd sets up a real breeding ground. The animals lie very close to one another so that each one occupies not more than 1 sq. m. The animals feel more confident in a large community and relax at leisure, convinced that they will not miss any danger if they keep together. When alarmed sea otters grab their cubs and rush to the sea where there are no enemies except killer whales.

Sea otters are quite good swimmers. On the surface they swim like dogs, but underwater they only use their hind legs and tail. The animals swim on the surface and only dive for short periods (evidently not very deep), swimming underwater for about a hundred metres. The air interlayer in the thick fur gives them great buoyancy, allowing the animals to rest on their backs floating on the water's surface.

Sea otters feed on various food. Sea urchins are the most significant and nutritious part of their diet. The high-calorie food helps them to survive the cold winter. Then come bivalve molluscs, for example, mussels and octopi. When fish schools approach the coast, the animals arrange for a meal of fish. Crabs are another seasonal dish that sea otters feed on with great appetite. When the animals are hungry they may devour a star fish or a holothurian, but do so without pleasure. Sea otters are gluttonous creatures. An adult ani-

mal needs 10,000 calories to cover its daily energy expense, that is 10-15 kg of sea otter's usual food.

The sea is the dining room for the animals. Sea otters take into the sea food they find ashore. Lying comfortably on its back and arranging five or six sea urchins on its chest, the animal will eat them one after the other. The treatment of sea urchins requires certain carefulness. At first, a sea otter will twist the urchin in its paws, studying it, then, having crumpled the spines, breaks through the bottom part of the shell, sometimes gnawing its edge, and, reaching the tasty inner organs, licks out the inside of the shell or empties it with a paw directly into its mouth. The Californian otters use a stone to break the shell. Prior to the hunting, the otter finds a heavy 3-4 kg cobble-stone. The animal uses this tool for a long time, carrying it under its arm while swimming. When the sea otter has caught sufficient number of urchins and molluscs, it arranges the stone on its chest and, holding the mussel in the paws, breaks its shell by striking it against the stone. The animals are also believed to employ the stone to tear off the molluscs that are tightly attached to the rocks.

Sea otters do not catch fish with their teeth but by using their paws. Strange as it may seem they can do this quite easily. They devour the fish only at the water's surface. They eat their food in the usual manner, lying on their backs, while holding a large fish in their paws. They tear off one strip of tender fillet after another, extending from the water to the waist. The bones and intestines of the food are discarded.

The females deliver their young ashore, having first found a hiden site, for example, a lonely rock or stone covered with a heap of seaweeds left behind by the waves. For some rare exceptions usually only one cub is born. It can see, and has teeth, albeit milk teeth. The little animal is covered with light-brown fur. Despite the seeming good development, the young one is utterly helpless for the first few weeks after birth. The mother never leaves it alone, even

for a minute. Going down the rocks, she takes it in her teeth and carries it on her chest in the water, holding it with a paw or her teeth, and dives with her baby in case of danger. After the young one has grown a bit, it floats vertically, and the mother pushes it in front of her.

Newly born sea otters can neither swim, nor dive and they must be taught. However, they never drown as their weight is considerably less than that of water. Diving in search of food, the mother leaves her baby for a minute on the surface and it floats on the waves with its belly up. The young sea otter learns to turn over on its belly and swim slowly with its paws after only three or four weeks. It learns to dive a little later. It knows no methods of protecting itself against enemies. If the mother departs for a minute to hunt but then notices some danger, she grabs the young one from beneath without surfacing and pulls it down.

The mothers are tenderly attached to their offspring. If a baby is caught, a mother will sometimes remain next to it. She devotes all of her free time to her child. The mother carries her baby on her chest, washes it with water, and rubs its fur with her paws to make it more fluffy. The fur plays an important role in the life of sea otters. When it is clean, it cannot be wetted and hence will not freeze. This is very important for the young ones. The life of the adult animal depends totally on the state of its fur. Scientists have often observed sea otters entering an oil film on the water surface. At first the animal dives and turns round and round in an attempt to wash off the oil. But, as this is impossible, the fur gradually becomes wet and the animal begins to freeze. Its movements turn slower and slower and, finally, the animal dies. The life of this valuable animal has met its end.

Sea otters are adapted for life in the sea as are their offspring, but solid land is still important for them. It provides them with shelter in bad weather, permits sick and wounded animals to recover, and is where they deliver their

offspring. Zoologists believe it may be possible that the cubs can be delivered in the water too in good weather in the thickets of seaweed. However, most of the young are born ashore. Only some 10,000 years ago, when oceanic islands were uninhabited and no large land predators were wandering about, the females would select sites for delivering their offspring quite far from the coast, and, evidently, went hunting without their cubs.

Everything indicates that sea otters are new to the sea, so to say, they are recruits in the army of aquatic mammals. A sea otter cannot survive without land and unlike other aquatic mammals can only eat on the water surface. It is unable to stay for a long time underwater. The hunting usually requires a minute but sometimes continues for two to three minutes. The animal only dives for a longer time in case of extreme danger.

Sea otters have retained many of the features of land animals in memory of their life ashore. It is necessary to mention first the ear conchae. Only a few species of seals have them in the family of aquatic mammals. In addition sea otters are the only marine creatures lacking protective subcutaneous fat under their fur. The otter's fur keeps the animal quite warm but it is unreliable as it may become wet and so it is not adapted for long periods in water. Fat is excellent heat insulator but it is also a reserve of food, allowing an animal to endure a long storm. It is quite possible that evolution will lead to its appearance and a site already exists for the fat. Recall the oversized fur-coat on the animal's body, it has sufficient space beneath it for a warm fatty lining.

All that is known about the life of sea otters has been accumulated by observing the animals in the wild and partially in open-air cages. The sea otters have not yet been studied in laboratories. One animal was brought to Leningrad at the beginning of the war, but it perished soon due to the lack of sufficient care. Hence, nothing is known for

certain about the functions of its sense organs. There is only mere guess-work. Zoologists considered for many years that the sense of smell is most developed in sea otters, but observations of animals in captivity do not confirm this. The animals sense fish, which they devour with the greatest pleasure, only from a very short distance. It is doubtful that the animals could use olfaction underwater because their mobile nostrils close when they dive.

Evidently, the sense of touch is the major analyzer of the sea otter. The animal has several groups of vibrissae: four 3 cm long vibrissae above each eye, three short ones on either side of the nose, and 120-150 vibrissae 6-7 cm long on the upper lip. Besides these, vibrissae are found on the chest and the fore paws. When huntingt, the otters rummage the sea bottom with their mustaches. They grab their prey blindly with their paws assisted by vibrissae.

It is considered that a sea otter's vision is weak, but this is hardly true. At any rate, they see no worse than a dog does. They can easily recognize people by their appearance, and it is difficult to approach them unnoticed.

Zoologists have also discredited the sea otter's sense of hearing. The reason for this was that captured animals did not react to noise. But why should their behaviour be different? Inhabitants of coastial regions become accustomed to the roar of the waves. It seemed to the scientists that the animals did not even understand where the sound originated. Sea otters are not paniced by the droning of a helicopter. But they can perceive natural sounds, for example, a water splash, causing an instantaneous orienting reaction.

The sea otter's cry is quite unique but its acoustic characteristics have not been investigated yet. A short loud cry is evidently a call signal; a young one calling its mother cheeps, while a special cry indicates danger. The animals are very sensitive to signals used for communication.

Nothing has been discovered about the ability of sea otters to produce sounds underwater. It is unclear whether

they perceive audio signals in water and whether they can determine where they come from. The auditory system of the sea otter differs very little anatomically from that of land mammals. The internal ear is not isolated from the skull as it is in dolphins. However, there is no reason to doubt the good sense of hearing in sea otters. Poor or no vision is widespread in the animal kingdom though weakening of the sense of hearing in some species of animals occurs rarer. Hearing is never poor if sound stimuli are important for the animals. Sea water is an excellent medium for the propagation of sound, and the need to move from one place to another at night or in turbid coastal waters demands some sort of orientation, primarily, an active orientation system. Nature could not invent anything better than echolocation for wandering about in the darkness! No data are available confirming the existence of this ability in sea otters, but one may assume it should be discovered in time, though it may not be very highly developed.

Sea otters are interesting to bioacousticians because they are the last mammals to have migrated to the ocean. It is possible that investigating them will assist in determining the stages in the development that the sound-producing and sound-perceiving systems of the animal pass through in order to attain the perfection of the cetacean's sonar. An evolutionary approach considerably facilitates an investigation of the complex functions of the organism.

WINGED PEDESTRIANS

The attempt of vertebrates to migrate to land, undertaken by fish, was only successful with reptiles. Despite the magnificent success of this enterprise, life ashore did not satisfy for some reason many of them, and they made the drastic and, it should be recognized, quite successful attempts to return to the sea. Present day crocodiles and many

species of turtles spend all their life in the water and only crawl ashore during the reproduction period to lay eggs. There are even species of lizards that have adapted well to aquatic life; sea snakes are the most successful. They are born and spend all their life in the ocean far from the coast, and never go ashore. A sea snake is helpless if a storm throws one onto a sandy beach.

The aquatic mode of life seemed attractive to many creatures. We have discussed earlier that there are many repatriates in the mammalian community who returned to the ocean and lost all their bonds with the land. Only birds mostly resisted the temptation to become truly aquatic creatures, though some species do spend almost all their life wandering over the ocean. However, even they can only land on the water surface and have never learned to dive.

Only penguins may be considered to be marine birds, though they neither fly, nor run. Penguins are quite clumsy on land. They walk on ice and frozen snow slowly, waddling on their feet, and if in a hurry they try to swim even on land. Flopping down on its belly and energetically working with its flippers and feet, a penguin can slide rapidly over an icy surface like a miniature snowplane.

Penguins are clumsy and awkward on land but they are good pedestrians. They make excellent paths around their breeding grounds. Penguins annually migrate for long distances, walking a considerable part of the route. The American Antarctic expedition found several years ago traces of an Adelie penguin 400 km from the nearest coast in the Ellsworth Mountains. Unfortunately, the American scientists could not determine whether the little explorer had gone barefoot to the South Pole.

There are 15 species of penguins today on the planet. They are usually depicted among ice-fields and snow-drifts. Indeed, most penguins inhabit the cold regions, but only the Emperor, King and Adelie penguins live permanently on the ice. The others have no objections to relaxing in the grass

and basking in the sun during the warm season. Finally, there are penguins that prefer to live in quite warm countries: on the coast of Australia, in South America and Africa, including the tropical zones of these continents if there are cold streams there, and the Galapagos penguin lives at the equator. It is not the love for the cold that forces penguins to seek cold water, but the abundance of food therein. Penguins observe one more rule in selecting their habitat: they never swim into the northern hemisphere; they are brought there only in cages.

Evidently, Europeans have known about penguins for a long time. They certainly met the winged pedestrians on the southern coast of Africa. However, the birds became widely known after the expeditions of Magellan round South America. Following witty exclamations of a participant of the expedition called Antonio Pigafett the "strange geese" were called "penguins", which in Latin means "fatty". This nickname was recognized universally. The scientific name for penguins, also Latin, means "wedgelike".

Penguins are large animals. The largest species, the Emperor penguins, range from 110 to 120 cm in height and weigh up to 45 kg. A King penguin is 90-95 cm in height, the Jackass penguin grows up to 85 cm, the Adelie and the Yellow-crowned penguins grow up to 80 cm, while the Macaroni penguin grows up to 75 cm. Only the Fairy penguin is a real pygmy, hardly reaching 40 cm in height.

The winged pedestrians resemble fat-nosed humans, especially when they walk in single file one after another. Their wings have modified into elegant flippers. From a distance they look like funny little humans gesticulating. The flippers are an amazing invention of nature. While swimming underwater, penguins do not so much use them for paddling, as for rotating them like propellers. It is a very economic method of movement because there are practically no losses in time or energy consumption for the idle run of the flippers. This is why the muscles that lift the wing are not less

developed than the muscles of the stroke, and sometimes they are larger and more powerful. In general, the flippers are driven by a powerful muscle motor, which quite often weighs about 1/4 of the total body weight. This is a great deal because about a half of the penguin's weight is due to fat.

The feet of the pedestrians are very short, and the long fingers are webbed. They are at the end of the body, thereby allowing penguins to take a vertical position. The tail (it has 16-20 feathers) is also very short. The birds use them as a portable stool. Resting on the tail, penguins spend several hours immobile in friendly company at a site protected against the wind.

The everyday overalls, that birds parade in, may be taken for a tail-coat with a snow-white shirt underneath. Their luxurious "evening dress" is "woven" from small feathers that cover the body densely and resemble scales. The "overall" has a thick fatty lining on the inside, which is also a store of food. This reserve is used during the long fasts ashore, where it is impossible to find anything to eat.

Penguins are monogamous and couples are very attached to each other, although anything may happen in family life. The head of the family may scream at its better half and even spank her. The family only stays together when hatching eggs and rearing the chicks. The rest of the time they live separately. Hence, the marriage is not for the whole life. If a female is late in returning to the breeding grounds, she risks finding her grieving husband hoarse from heartbreaking wailing, but married to another one. The adulterer will not leave his new wife, at any rate until the next breeding period, and will not become a bigamist. The abandoned wife can do nothing else but seek a new husband.

The birds gather into large colonies for breeding, sometimes numbering a half million pairs. The colonies also contain one and two-year old birds, who are too young for marriage, but nevertheless have to learn family ways. The col-

onies settle on peaty meadows, low stony shores, sandy dunes, rocks (not necessarily near the coast, Crested penguins being excellent rock-climbers), while Emperor penguins gather in their colonies directly on the ice.

Each species of penguins breeds in its own favourite season. For some obscure reason Emperor penguins breed during the coldest and darkest part of the winter. Adelie penguin is another species that breeds in the Antarctic continent, but they do so in summer. It is dangerous to nest on the ice during this time of the year, which is why they seek nesting sites on the most windy spots where the snow is blown away totally. Even if the polar sun is unable to melt pools on the snow surface, the hot body of the penguin will inevitably make a bath with melt water during the warm season and the hopes of the parents to have offspring will get drowned together with the eggs.

King penguins lay their eggs at the very beginning of summer, otherwise the chicks would not grow up enough by autumn and their chances to survive the severe winter would be small. Jackass penguin inhabiting the southern coast of Africa breeds all the year round. These birds living closer to the Equator, and the Galapagos penguins hatch their chicks during the cool season.

The nest of a penguin is quite simple. The birds build a nest with stones, bones, and plant stalks. The male will bring the building materials and the female builds and protects the nest. Adelie penguins use last year's dung for nest construction while Jackass penguins, which live closer to the Equator and hatch their chicks during the rainy season, are unable to use building material they produce themselves. They lay the eggs directly in the grass and seek a new nesting site each year because the previous one turns into a swamp of stinking fluid dung during the summer.

Fairy and Magellan penguins build the most perfect nests. They dig burrows in peatland or sand dunes. Emperor and King penguins manage without nests entirely. The males of

these species hold the single egg on their feet, covering it with a fold of skin that hangs down from the belly. The mating period begins with wooing. Emperor penguins return to nesting sites at the end of the Arctic summer. The assembly lasts a month. The birds are indifferent to one another at this time and wait for the right date. At the beginning of April the males begin to wander in the colony among the thousands of others and wail. A few days may pass by until a female responds to his call, which is expressed by a peculiar sound, a song of "seduction". However, if his spouse has returned by this time, she will not make him wait long. The female recognizes her beloved one by voice. Drawing close together and, sometimes, pressing to one another with highly lifted heads and half-closed eyes, the happy couple stands still in ecstasy. The marriage contract is resigned.

Having finished all the formalities, the newly-weds spend the rest of their time phlegmatically until the female lays an egg by the end of the fourth week. The delivery takes a long time and is agonizing. The male is very worried during this time and humbly endures a beating from his wife if she is irritated. In the end the egg is laid. The couple greets this event quite emotionally.

The egg of Emperor penguin is large and weighs up to half a kilogram. The female prevents its cooling by rolling it onto her feet while the male sings a love song to his beloved spouse. At first the male seems to be satisfied but he begins to realize that he must possess the egg to experience complete happiness. He makes low bows before his wife which she returns and starts to sing. The male takes the second part and tries to grab the egg in the intervals between the arias. When he is lucky enough to hold the egg, he stands quite still, and loses immediately all interest in the surroundings. Sensing the coolness of her husband, the female walks away but soon returns for a short time to check whether the egg is in safe hands.

The female fasts from the moment she lands on the ice and becomes quite emaciated. She ought to hurry to the sea but she will return many times. Each time she goes farther away from the colony until she meets two or three other empresses that have also been turned down, and the female company departs to recover their strength on the abundant marine food. The females only return to the colony two months later. During this time the males stand still in the same pose and huddle together only in snow-storms. They immediately disperse when the wind begins to fall.

The female usually returns before the chick hatches, bows to the male, takes the egg away, and allows him to leave for the sea. Sometimes the chick hatches before the mother has returned. Despite their four-month fast, the most conscientious fathers retain a little food in their crops. However, if the mother stays away too long, she risks finding her offspring dead.

The store of food in the female's crop for the young one ought to suffice for 1.5-2 months until the father brings a new store from the sea. The chick stays on its mother's feet all this time, blanketed by her belly fold. When the father returns, the chick is already too big for its mother's cradle. The funny little chicks gather in large communities and spend their time in improvised nurseries, where their parents find them when it is time for the next feed. They recognize their offspring unerringly by voice and never feed a strange chick. They might adopt a strange chick only if they lose their own offspring. By contrast, young bachelors quite actively express their wish to become guardians. The young ones accept nonchalantly any guardian if they are fed.

King penguins hatch their chicks the same way, the only difference being that the hatching period is a little shorter and the parents replace one another more often. The normal clutch of the Adelie penguins is two eggs, which they incubate like other birds. The incubation period lasts for 33-40 days. The female Macaroni penguin also lays two eggs

but often only the second egg is incubated. The Fairy penguin produces the greatest number of chicks, and three little chicks are frequently found in their nesting burrows.

Penguins are excellently adapted to life under the severe polar conditions. The most terrible hazard for them is the hard frost and the dearth of food, but they can fight both. Feeding on fry, small squids and cuttlefish, birds build up a sizable store of fat.

Gentoo penguins, inhabiting the Posesyon Island in the Antarctic, manage to maintain a body temperature of 39.8 °C even when the temperature falls to minus 40-50 °C and in piercing wind. To do this, they spend 150 g of fat from their store per day, which is about 2 % of their body weight. Having fed well in the ocean, penguins can go ashore and relax for several days without thinking about food. Their reserve of fuel satisfies them for two weeks.

It is more difficult for the birds that inhabit the Antarctic continent. Emperor penguins spend a large amount of fat in order to keep from freezing. Their weight drops about 200 g per day when the frost is hard. During snow-storms and when the temperature falls drastically about 300-600 penguins huddle together into a tight mass, forming a "tortoise". Standing close together they warm each other, and so their consumption of fat reduces by 50 %. The "tortoise" is constantly moving. The birds exposed to the wind slowly move around the community, and the "tortoise" can move 100-150 m per day.

Penguins are similarly well adapted to living in water. The thick layer of fat is once again their protection against the cold water temperature. They are unable to breathe underwater, but they have learned to store oxygen better than any other species of birds. They contain a record amount of blood: 15 % of the body weight, and the amount of haemoglobin in each erythrocyte is 2-2.5 times greater than in ducks or geese. If it is considered that the erythrocytes occupy half the blood volume and the muscles comprise myo-

globin, it becomes clear how penguins can stay underwater up to 7 minutes.

There is no reason to stand on ceremony on the uninhabited Antarctic shores. Hence, the penguins are quite noisy. They use special poses and sound signals for communication. The seduction song of Emperor penguins resembles fast chattering with a drawling note at the end. The blaring call whistle is heard several kilometres away. They produce cries of terror, anger, and satisfaction. The latter resemble gurgling and are emitted only in water. The favourite signal of Fairy penguins is a sound that resembles bleating.

The vision of the penguins is well-developed like that of most birds. However, hearing is more important for these birds. When their eyes were pasted up, the penguins calmly returned to their colony. However, when the acoustic meatuses were pasted up, they turned round and round in complete perplexity, though their colony was well within sight.

It would be useful for penguins to possess echolocation, as it is for all animals that feed underwater. Scientists in Moscow first began to study the echolocation system of penguins. It turned out that King and the Macaroni penguins underwater occasionally emit ultrasounds with a frequency up to 300 kHz. They generated sounds in series, as it is done in the case of echolocation. It was determined that the ultrasound pulses were generated by four independently controlled sound generators acting together.

Researchers assume that penguins possess sonars too. In the hopefully not too far distant future we will see whether this assumption is correct and why penguins need location pulses with such a high resolving power.

Bioacoustics is a very young science. Scientists have discovered in a comparatively short time several dozen animals that have mastered echolocation. Bats are the most talented land animals.

It is simpler to use echolocation underwater. The condi-

tions for sound propagation are incomparably better in water than in air, and this is where echolocation is widely applied by animals.

Whales and dolphins are the best acousticians of the ocean. They are large animals with big well-developed brains. They possess excellent generators and reliable hydrophones. Compared with a bat, they possess much better brains for comprenhensive analyzing the information obtained by means of echolocation. Bioacoustics will assist in understanding many features of the life of the animals that live in the oceans of the world. It is high time for humanity to learn to control and manage these biological processes, and utilize reasonably the resources of the biosphere, particularly the hydrosphere. The fate of the mankind depends greatly on all these factors. Bioacoustics, a science that emerged at the interface of two disciplines and equally serve biology and engineering, plays a major role in studying the biology of the seas.

TO THE READER

Mir Publishers would be grateful for your comments on the content, translation and design of this book.
We would also be pleased to receive any other suggestions you may wish to make.
Our address is:
2 Pervy Rizhsky Pereulok
I-110, GSP, Moscow, 129820
USSR

Printed in the Union of Soviet Socialist Republics

This book concerns that mysterious world that lies beneath the ocean waves. From antiquity until relatively recently people have thought it was a silent world, but scientists now realise that marine life is in fact quite noisy. Myriads of underwater creatures, such as dolphins, whales, and seals, obtain information in a way quite incomprehensible to us, Homo sapiens, for they use sonar or echolocation. Many terrestrial animals use echolocation to see and hear in conditions in which human beings are deaf and blind. 'What is echolocation?' and 'How do wild animals use it to obtain information?' are just some of the questions answered in "The Living Sonars of the Ocean" by B. Sergeev.

This book concerns that mysterious world that lies beneath the ocean waves. From antiquity until relatively recently people have thought it was a silent world, but scientists now realise that marine life is in fact quite noisy. Myriads of underwater creatures, such as dolphins, whales, and seals, obtain information in a way quite incomprehensible to us, Homo sapiens, for they use sonar or echolocation. Many terrestrial animals use echolocation to see and hear in conditions in which human beings are deaf and blind. 'What is echolocation?' and 'How do wild animals use it to obtain information?' are just some of the questions answered in "The Living Sonars of the Ocean" by B. Sergeev.